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Quod si cui mortalium cordi et curæ sit non tantum inventis hære, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant.  
—*Novum Organum, Præfatio.*

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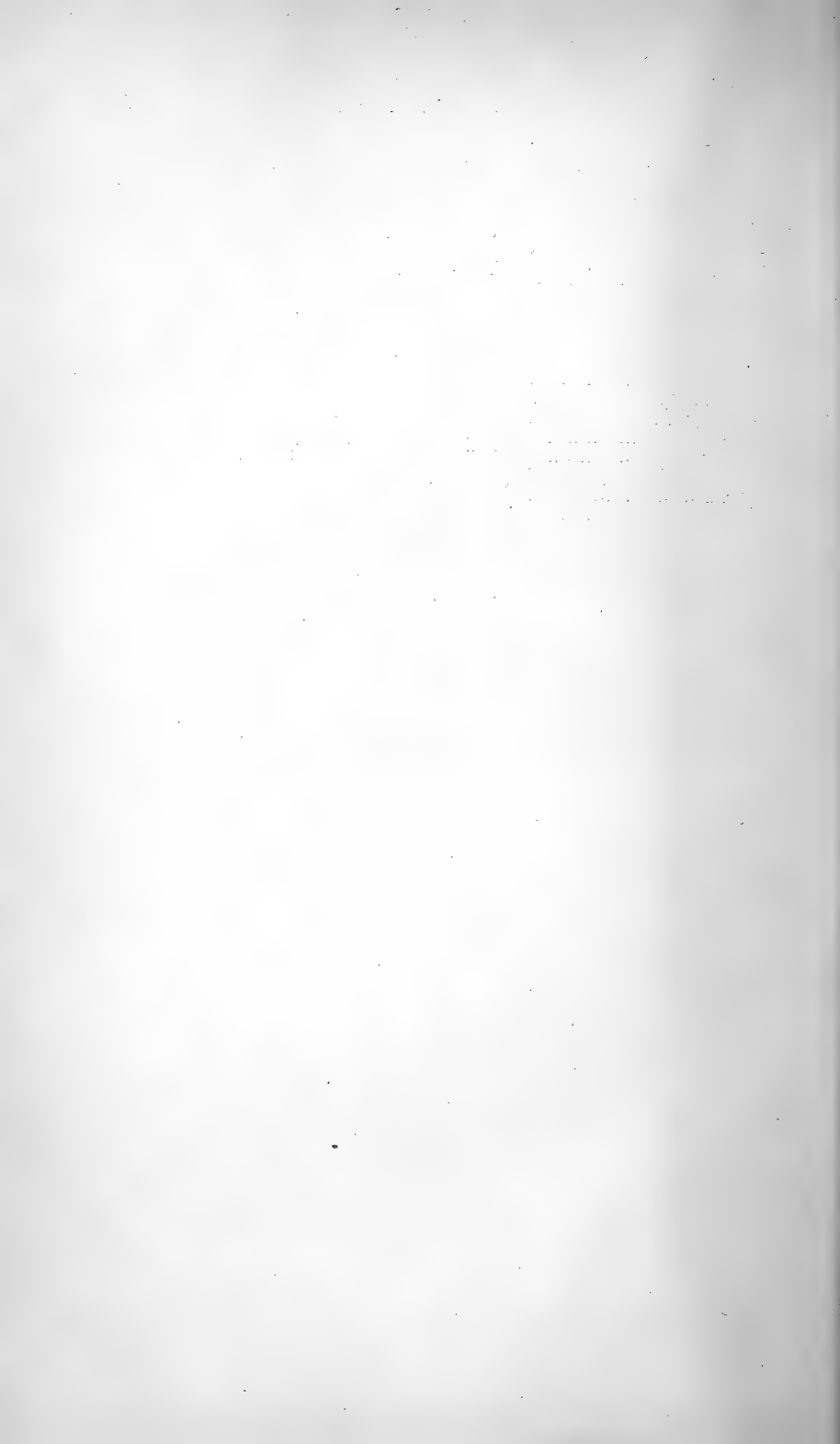
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#### ERRATA.

- P. 51. The tabulated comparative measurements of metacarpals are to be read as given in inches, *not* in millimetres.
- P. 424, line 13 from the top. *For* 'St. Mary's-Well Bay, Sully' *read* 'Cadoxton.'
- P. 470, line 19 from the bottom. *For* 'Halicodiadema' *read* 'Helicodiadema.'

#### VOL. LX (1904).

- P. 394, second footnote. *For* 'vol. iii (1891-92)' *read* 'vol. iv (1893-95) p. 90'; *and add* 'Trans. Manch. Geol. Soc. vol. xxiii (1894-95) p. 65.'



PROCEEDINGS  
OF THE  
GEOLOGICAL SOCIETY OF LONDON.

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SESSION 1904-1905.

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November 9th, 1904.

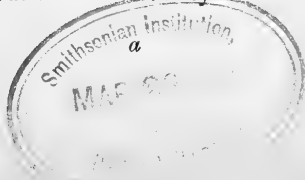
J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Edward Battersby Bailey, B.A., of H.M. Geological Survey, 49 Alleyn Park, Dulwich, S.E.; Davidge Page, Assoc.M.Inst.M.E., F.C.S., F.R.G.S., Hotel Russell, Russell Square, W.C.; Edward Heton Robertson, B.A.Oxon., Lecturer in Mining in the University of Birmingham; and Arthur Young, M.A., B.Sc., Professor of Geology & Mineralogy in the South African College, Cape Town, were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. E. T. NEWTON, in exhibiting, by permission of the Director of H.M. Geological Survey, a specimen of *Fayolia* near to *Fayolia grandis*, found by Dr. L. Moysey, of Nottingham, in the Coal-Measures of Ilkeston (Derbyshire), pointed out that *Fayolia* was first described by Profs. Renault & Zeiller in 1884, in their monograph on the 'Houiller de Commentry.' In 1894 Mr. Seward described the first British specimen, from Northumberland, in the Leeds 'Naturalist,' but thought that it was not a plant. There was some resemblance to certain spiral egg-cases of Elasmobranchs; but Dr. Günther was unwilling to accept the Northumberland fossil as the egg-case of a fish. Mr. Kidston had not yet seen the specimen now exhibited; but, from a sketch, he recognized its relation to *Fayolia*. At present, there was still uncertainty as to the exact nature of this fossil.

VOL. LXI.



The following communications were read :—

1. 'Notes on Upper Jurassic Ammonites, with Special Reference to Specimens in the University Museum, Oxford: II.' By Miss Maud Healey. (Communicated by Prof. W. J. Sollas, Sc.D., LL.D., F.R.S.)<sup>1</sup>

2. 'Sarsen-Stones in a Claypit.' By the Rev. E. C. Spicer, M.A., F.G.S.

3. 'On the Occurrence of *Elephas meridionalis* at Dewlish (Dorset). Second Communication: Human Agency suggested.' By the Rev. Osmond Fisher, M.A., F.G.S.

In addition to the fossil mentioned on the preceding page, the following specimens, etc. were exhibited :—

Specimens of Upper Jurassic ammonites, exhibited in illustration of the paper by Miss Maud Healey.

Sarsen-stones and lantern-slides, exhibited by the Rev. E. C. Spicer, M.A., F.G.S., in illustration of his paper.

Specimens, photographs, and lantern-slides, exhibited by the Rev. O. Fisher, M.A., F.G.S., in illustration of his paper.

Flint (scraper?) found in a gravel-seam in the Cromer Forest-Bed, near Runton Gap, exhibited by O. A. Shrubsole, F.G.S.

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November 23rd, 1904.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Ellis Wright Heaton, B.Sc., 55 Thorold Road, Ilford (Essex), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On an Ossiferous Cavern of Pleistocene Age at Hoe-Grange Quarry, Longcliffe, near Brassington (Derbyshire).' By Henry Howe Arnold-Bemrose, J.P., M.A., F.G.S., and Edwin Tulley Newton, F.R.S., V.P.G.S.

2. 'The Superficial Deposits and pre-Glacial Valleys of the Northumberland and Durham Coalfield.' By David Woolcott, D.Sc., F.G.S.

<sup>1</sup> Withdrawn by permission of the Council.

The following specimens, etc. were exhibited :—

Fossil-bones, photographs, and lantern-slides of the ossiferous cavern at Hoe-Grange Quarry, Longcliffe, exhibited by H. H. Arnold-Bemrose, J.P., M.A., F.G.S., and E. T. Newton, F.R.S., V.P.G.S., in illustration of their paper.

Maps and lantern-slides, exhibited by David Woolacott, D.Sc., F.G.S., in illustration of his paper.

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December 7th, 1904.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Charles Wilgress Anderson, Lyndhurst, Main Street, Georgetown (British Guiana); Lionel C. Ball, B.E., Assistant Government-Geologist, Department of Mines, Brisbane (Queensland); George Marmaduke Cockin, M.Inst.M.E., Mining Engineer, Brereton Hall, Rugeley; Arthur Edwin Dixon, Hampson's Collieries, Waschbank (Natal); Sydney Fawns, 5 Sussex Mansions, South Kensington, S.W.; Hartley T. Ferrar, B.A., Sidney Sussex College, Cambridge; George Herbert Fowler, B.A., Mining Engineer, Basford Hall, Nottingham; Reginald Walter Hooley, Ashton Lodge, Portswood, Southampton; C. Baring Horwood, A.R.S.M., Assoc.M.Inst.C.E., P.O. Box 1030, Johannesburg (Transvaal); Cosmo Johns, M.I.M.E., Burngrove, Pitsmoor Road, Sheffield; William Dickson Lang, B.A., Cricketfield Cottage, Harrow; William Lockett, Oakwood, High Lane, Burslem (Staffordshire); the Rev. James Dunne Parker, D.C.L., LL.D., Bennington House, Bennington, Stevenage; Thomas William Faraday Parkinson, M.Sc., 80 Ainsworth Road, Radcliffe; B. Jaya Ram, Assistant Geologist, Geological Survey of Mysore, Bangalore (India); and William Bourke Wright, B.A., H.M. Geological Survey, 28 Jermyn Street, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read :—

‘On the Chemical and Mineralogical Evidence as to the Origin of the Dolomites of Southern Tyrol.’ By Prof. Ernest Willington Skeats, D.Sc., F.G.S.

The following specimens, etc. were exhibited :—

Rocks, microscope-sections, and lantern-slides, exhibited by Prof. E. W. Skeats, D.Sc., F.G.S., in illustration of his paper.

Plan of the Eastern Extension of the Witwatersrand, showing the main geological features, etc., by J. I. Hoffmann, presented by the Author.

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December 21st, 1904.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

P. Charteris A. Stewart, Assoc.R.S.M., 51 Redcliffe Square, S.W.; and William Hutton Williams, Assoc.R.S.M., Homefield, The Grove, Ealing, W., were elected Fellows; and Prof. Giuseppe de Lorenzo, Mineralogical Museum, Royal University of Naples, was elected a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On Certain Genera and Species of *Lytocerotidæ*.' By S. S. Buckman, F.G.S.
2. 'The Leicester Earthquakes of August 4th, 1893, and June 21st, 1904.' By Charles Davison, Sc.D., F.G.S.
3. 'The Derby Earthquakes of July 3rd, 1904.' By Charles Davison, Sc.D., F.G.S.
4. 'Twin-Earthquakes.' By Charles Davison, Sc.D., F.G.S.

The following specimens, etc. were exhibited:—

Specimens of *Lytocerotidæ*, exhibited by S. S. Buckman, F.G.S., in illustration of his paper.

MS. geological map of the Charnwood-Forest district, and lantern-slides, exhibited by Prof. W. W. Watts, M.Sc., F.R.S., Sec.G.S., in illustration of Dr. Davison's paper on the Leicester earthquakes.

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January 4th, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Oswald Hardy Evans, Pacific Smelting Co., Ltd., Taltal, Atacama (Chile), and Dr. A. Wollemaun, 3 Bammelsburgerstrasse, Brunswick (Germany), were elected Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: H. W. MONCKTON, F.L.S., and H. BAUERMAN, Assoc.M.Inst.C.E.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Marine Beds in the Coal-Measures of North Staffordshire.' By John T. Stobbs, Esq., F.G.S. With Notes on their Palæontology by Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S.

2. 'The Geology of Cyprus.' By Charles Vincent Bellamy, M.Inst.C.E., F.G.S. With Contributions by Alfred John Jukes-Browne, B.A., F.G.S.<sup>1</sup>

The following specimens were exhibited :—

Specimens from the Marine Beds in the Coal-Measures of North Staffordshire, exhibited by Wheelton Hind, M.D., F.G.S., J. T. Stobbs, F.G.S., and John Ward, F.G.S., in illustration of the paper on that subject.

Specimens of *Archæocidaris* allied to *A. vetusta*, Phillips, and *A. benburbensis*, Portlock, from the grey shale underlying the Gin-Mine Coal, Nettlebank Colliery, Smallthorne (Staffordshire), exhibited by Dr. F. A. Bather, M.A., F.G.S.

Microscope-sections of rocks from Cyprus, exhibited in illustration of the paper by C. V. Bellamy, M.Inst.C.E., F.G.S., and A. J. Jukes-Browne, B.A., F.G.S.

*Clypeaster altus* var. *portentosus* (Helvetian) from Cyprus, and microscope-sections of the matrix. Collected by Miss D. M. A. Bate, and exhibited by Dr. F. A. Bather, M.A., F.G.S.

---

January 18th, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

Mr. W. G. FEARNSIDES, in exhibiting a series of Llandovery-Tarannon graptolites from Llanystumdwy, near Criccieth (Caernarvonshire), remarked that the graptolites were beautifully preserved in pyrites, and were in full relief. They were from shales of the Birkhill or Stockdale-Shale type, and the four zones of *Monograptus exiguus*, *M. turriculatus*, *M. fimbriatus*, and *Dimorphograptus* were indicated. This was the first record of Llandovery-Tarannon rocks in the Lleyen Peninsula, since the time of Salter's Catalogue, which recorded Llandovery fossils of May-Hill type from The Hollies Farm, Pwllheli.

Mr. G. F. HERBERT SMITH, in exhibiting a hand-refractometer, remarked that, in that instrument, he had endeavoured to produce a refractometer which should be portable, and at the same time should furnish results of sufficient accuracy for the practical requirements of the mineralogist and the petrologist. The

<sup>1</sup> Withdrawn by permission of the Council.

refractometer designed by Prof. E. Bertrand in 1885 was portable, but in it no attempt had been made to compensate for the curvature of the hemisphere. The focal surface corresponding to the hemisphere was—apart from the effects of chromatic and spherical aberration—for rays which were parallel inside the glass, a spherical envelope concentric with the hemisphere. Hence the ocular scale could not possibly coincide with the focal surface for the whole range required, and the difficulties owing to parallax and bad definition of the shadow-edge rendered accurate results impossible. He (the speaker) had, in the present instrument, overcome this defect by introducing between the hemisphere and the scale a corrective lens, by means of which the focal surface became almost exactly a plane, and the edges separating the light and dark fields were sharply defined throughout the whole range.

The scale was graduated by means of observations on known substances. Each interval corresponded to a difference in refractive indices of about 0.010. In monochromatic light the shadow-edge appeared as a delicately-traced line, and an estimate of the refractive index might be obtained correct to two units in the third place of decimals. The instrument had been constructed to give the best results between 1.45 and 1.75. The glass of which the hemisphere was composed had a refractive index of 1.7938.

The refractometer was to be used in the ordinary way. The indices of minute fragments might be determined indirectly, by finding with a microscope a liquid of the same refraction as themselves, and then observing with the instrument the index of the liquid.

Mr. J. H. Steward, of London, was the maker of this refractometer.

The following communication was read:—

‘On the Geology of Arenig Fawr and Moel Llyfnant.’ By William George Fearnside, M.A., F.G.S.

In addition to the exhibits described on pp. v–vi, the following specimens were placed on the table:—

Fossiliferous Arenig rocks and volcanic intrusives, with microscope-sections, exhibited by W. G. Fearnside, M.A., F.G.S., in illustration of his paper.

Reproductions of an interesting series of new sea-urchins, of the family Spatangidæ, recently found in blocks of a Middle Miocene rock, apparently brought up by ice-action from the floor of the Schaalsee, near Zarrentin (S.E. Holstein), exhibited by Dr. F. A. Bather, M.A., F.G.S.

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February 1st, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Charles Griffith, M.A., Barnes Close, Winchester; V.S. Sambasiva Iyer, B.Sc., L.C.E., Curator in the Mysore Geological Department and Lecturer in Geology at the Central College, Bangalore (India); George Maxwell Lawford, M.Inst.C.E., 9 Bridge Street, Westminster, S.W.; Walter Reginald Gibson Rivington, Assoc.R.S.M., Assoc.I.M.M., Normanhurst, Northwood (Middlesex); Franz Eduard Studt, 13 Moscow Road, Stockport; Carl Adolph Süssmilch, Lecturer in Geology, Mineralogy, and Mining at the Sydney Technical College, Sydney (N.S.W.); and Isidore Tom, Assoc.R.S.M., Pyrenees Minerals Ltd., Alzen Mines, La Bastide de Sérou, Ariège (France), were elected Fellows of the Society.

The List of Donations to the Library was read.

Prof. GARWOOD exhibited and commented on a set of twelve lantern-slides, illustrating the use of three-colour photography in demonstrating the microscopic characters of rock-forming minerals in polarized light.

Mr. A. P. YOUNG said that he would like to learn what were now held to be the three primary colours, the practice in this respect appearing to have undergone some changes since the early days of colour-photography.

Prof. WATTS pointed out the immense value of the photographs exhibited for teaching purposes. The colours were wonderfully accurate and beautiful; and, besides this, the refractive index was well-shown. He hoped that copies of these photographs might, some day, be available for teachers.

Prof. GARWOOD replied to Mr. Young that the slides were taken by the Sanger-Shepherd process, in which yellow, green, and red screens were used. In answer to a question from Dr. Teall, he said that it was not a process that could be used very easily, but one which required a good deal of time to produce really-accurate prints. Considerable difficulty was experienced in procuring objectives which were truly corrected for the spectrum, the tendency in the case of interference-figures being to give different-sized rings for different colours. He agreed with those who had taken part in the discussion, that the results did resemble very closely the phenomena seen under the microscope; and he had brought one or two rock-sections, shown on the screen, in case Fellows interested in the subject would like to compare the slides with the original sections.

The following communication was read:—

‘On the Sporangium-like Organs of *Glossopteris Browniana*, Brongn.’ By E. A. Newell Arber, M.A., F.L.S., F.G.S.

In addition to the slides mentioned on the preceding page, the following specimens and maps were exhibited:—

Specimens of *Glossopteris*, from Nagpur, Hislop & Hunter Collection, in the Museum of this Society; and specimens of *Glossopteris*, from the Permo-Carboniferous of New South Wales, exhibited by Dr. A. Smith Woodward, F.R.S., F.G.S., in illustration of the paper by E. A. Newell Arber, M.A., F.L.S., F.G.S.

Geological Survey of England and Wales: 1-inch Geological Map, n. s., Sheet 261–262 (Solid & Drift), by R. H. Tiddeman, T. C. Cantrill, & A. Strahan (colour-printed), 1905, presented by the Director of H.M. Geological Survey.

Five sheets of the Geological Map of the Auriferous Region of the Yenisei, by A. Meister, and one sheet of the Geological Map of the Auriferous Region of the Lena, by A. Gerasemov, scale 1 : 84,000, presented by the Imperial Russian Geological Survey.

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## ANNUAL GENERAL MEETING,

February 17th, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

### REPORT OF THE COUNCIL FOR 1904.

THE Society continues in a generally-flourishing condition, although there is a small decrease in the total Number of Fellows. During the year under review 46 Fellows were elected (the same number as in 1903, and 2 less than in 1902), of whom 31 paid their Admission-Fees before the end of the year. Moreover, 13 Fellows, who had been elected in the previous year, paid their Admission-Fees in 1904, the total accession of new Fellows during the past twelve months amounting, therefore, to 44 (5 less than in 1903).

Setting against this number a loss of 47 Fellows (28 by death, 13 by resignation, and 6 by removal from the List, under Bye-Laws, Sect. VI, Art. 5), it will be seen that there is a decrease in the Number of Fellows of 3 (as compared with a decrease of 4 in 1903, and an increase of 6 in 1902).

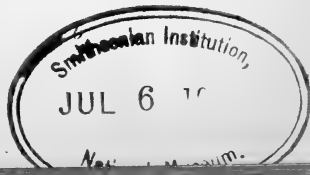
This brings the total number of Fellows down to 1251, made up as follows:—Compounders, 281; Contributing Fellows, 934 (4 more than in both 1903 and 1902); and Non-Contributing Fellows, 36.

Turning now to the Lists of Foreign Members and Foreign Correspondents, we have to deplore the loss of two of the former in 1904 (Prof. F. A. Fouqué and Prof. K. A. von Zittel), and also that of one Foreign Correspondent (Prof. C. E. Beecher). The vacancies thus created (as well as two in the List of Foreign Correspondents left over from 1903) were filled by the transfer of Prof. J. P. Iddings and Prof. H. F. Osborn from the list of Correspondents to that of Members, and by the election of Prof. W. B. Clark, Prof. E. D. von Drygalski, Prof. G. de Lorenzo, the Hon. Frank Springer, and Prof. H. S. Washington as Foreign Correspondents.

With regard to the Income and Expenditure of the Society during the past year, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—

The total Receipts, including the Balance of £192 6s. 11*d.* brought forward from the previous year, amounted to £3187 3s. 9*d.*, being £66 18s. 10*d.* more than the estimated Income.

The total Expenditure during the same period amounted to £2777 16s. 2*d.*, being £150 1s. 10*d.* less than the estimated Expenditure for the year.



The alterations in the Bye-Laws, necessitated by the new regulations which the Council at the time of the last Annual Report had in view (in regard both to the publication of papers and to the admission of Visitors to Meetings), were agreed to, at a Special General Meeting summoned for the purpose of considering such alterations. The regulations made by the Council in accordance with the revised Bye-Laws as to Visitors have been published in the Proceedings, and also certain regulations as to Exhibits at Meetings. The appearance of the names of Members of the Standing Publication-Committee, on the inside of the cover of each number of the Quarterly Journal, is an indication of the change that has been made in the method of selecting papers for publication.

The Council have to announce the completion of Vol. LX and the commencement of Vol. LXI of the Society's Quarterly Journal.

Mr. C. Davies Sherborn is making rapid progress with his manuscript Card-Catalogue of the Library, so rapid indeed that more cabinets have had to be purchased for the purpose of accommodating the Catalogue than could have been foreseen at the time when the Estimates for 1904 were framed. Mr. Sherborn has also undertaken to continue during the current year the preparation of the catalogue-slips for the International Catalogue of Scientific Literature.

The approaching centenary of the foundation of the Society suggested to Mr. H. B. Woodward the propriety of celebrating the event by the publication of a Record which should embody the history of the Society. He accordingly placed before the Council a sketch of the principal features of the proposed Record, and a small Committee, of which he is a member, has been appointed to carry out the scheme. There is every reason to hope that the work will be completed by the centenary year 1907.

In November, a further sum of £91 8s. 7d. was received from the executors of the late Sir Joseph Prestwich, making the total amount received on account of his bequest to the Society £709 2s. 10d., after deduction of legacy-duty. This additional sum has been invested in India 3 per cent. Stock, on account of the Prestwich Trust Fund.

The second Award from the Daniel-Pidgeon Trust-Fund was made, on May 11th, 1904, to Mr. Linsdall Richardson, who proposed to extend his researches among the Rhætic and Inferior Oolite formations, and to conduct excavations at Berrow Hill, near Upton-on-Severn.

The following Awards of Medals and Funds have also been made by the Council:—

The Wollaston Medal is awarded to Dr. J. J. Harris Teall, F.R.S., in recognition of the value of his 'researches concerning the mineral structure of the Earth,' and particularly of his valuable contributions to the science of Petrology in general, more especially to our knowledge of the structure and composition of the rocks of the British Islands.

The Murchison Medal, together with a Sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. Edward

John Dunn, of Victoria (Australia), in recognition of his valuable contributions to Geological Science in the form of geological maps of South Africa and researches on the modes of occurrence of gold in Australia.

The Lyell Medal, together with a Sum of Twenty-Five Pounds from the Lyell Geological Fund, is awarded to Dr. Hans Reusch, For.Memb.G.S., 'as a mark of honorary distinction and as an expression on the part of the Council that he has deserved well of the science,' especially by his contributions to our knowledge of the Geology of Norway.

The Bigsby Medal is awarded to Prof. John Walter Gregory, F.R.S., 'as an acknowledgment of his eminent services to Geology,' both in the departments of Stratigraphy and Palæontology, in many parts of the world.

The Balance of the Proceeds of the Wollaston Donation-Fund is awarded to Mr. Henry Howe Arnold-Bemrose, M.A., as an acknowledgment of the value of his investigations among the igneous rocks and cave-deposits of Derbyshire, and to encourage him in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Herbert Lister Bowman, M.A., in recognition of his services to Mineralogy, and as an encouragement to further work.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Edward Alexander Newell Arber, M.A., in recognition of his valuable contributions to our knowledge of Fossil Botany, and to encourage him in further investigations.

The other moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Walcot Gibson, B.Sc., as an acknowledgment of the valuable work done by him among the Carboniferous and other strata of the Midland Counties, and as an encouragement to further research.

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#### REPORT OF THE LIBRARY-AND-MUSEUM COMMITTEE FOR 1904.

The Additions made to the Library during the past twelve months have maintained, both in number and in importance, the standard of previous years.

During 1904 the Library received by Donation 141 Volumes of separately-published Works, 319 Pamphlets and detached Parts of Works, 261 Volumes and 48 detached Parts of Serial Publications, and 18 Volumes of Newspapers.

The total number of accessions to the Library by Donation is thus found to amount to 420 Volumes, 319 Pamphlets, and 48 detached Parts. Moreover, no less than 98 sheets of Maps were presented to the Library, 27 of which came from the Ordnance-Survey Department.

Among the numerous donations mentioned in the foregoing paragraphs, special attention may be directed to the following:— Report of the Coral-Reef Committee of the Royal Society on the Atoll of Funafuti; Prof. Zeiller's great monograph on the Flora of the Coal-bearing strata of Tongking; the official handbook on the Geology of the Cameroons, issued by the German Foreign Office; Prof. H. S. Washington's Manual of the Chemical Analysis of Rocks; Prof. Perner's Monograph on the Silurian Gasteropoda of Central Bohemia, Vol. I; Herr Hauswaldt's 'Interference-Phenomena in Polarized Light'; Vol. I of Miss Sollas's translation of Suess's 'Face of the Earth'; the Geological Survey Memoirs on the Kingsbridge and Salcombe Districts of Devon, on Merthyr Tydfil, on the Oolitic and Cretaceous Rocks south of Scarborough, on the country round Belfast, on the Tertiary Igneous Rocks of Skye, and the third volume of the 'Cretaceous Rocks of England.' From the Trustees of the British Museum the following volumes were received: Vol. I of the 'History of the Collections in the Natural History Department'; Vols. I & II of Mr. B. B. Woodward's Catalogue of the Library of that Department; Vol. II of Mr. A. C. Seward's Catalogue of the Jurassic Flora; Mr. L. Fletcher's 'Introduction to the Study of Meteorites'; and Dr. A. S. Woodward's 'Guide to the Fossil Mammals & Birds.' From our Foreign Member, Prof. G. K. Gilbert, the volumes on 'Glaciers & Glaciation,' and 'Geology & Palæontology' of the Report of the Harriman Alaska Expedition were received; and our Foreign Correspondent, Dr. Th. Thoroddsen, presented to the Library a large collection of copies of his papers issued during the last 20 years. Moreover, numerous publications were received from the Geological Survey Departments of Egypt, India, Natal, the Transvaal Colony, Victoria, Hungary, Russia, Mexico, Ohio, and the United States.

In addition to the Ordnance-Survey maps mentioned in a preceding paragraph, 15 Sheets of Maps were received from H.M. Geological Survey; 16 Sheets from the Geological Survey of Canada; 9 Sheets from the Geological Survey of Western Australia; 8 Sheets from the Geological Survey of Italy; and 5 Sheets from the Geological Survey of Japan. Mr. H. B. Woodward presented a copy of his new edition of Stanford's Geological Atlas of Great Britain; and Dr. F. H. Hatch sent in a copy of the new edition of his Geological Map of the Southern Transvaal.

The Books, Maps, etc. enumerated above were the gift of 162 Personal Donors; 113 Government Departments and other Public Bodies; and 157 Societies and Editors of Periodicals.

The Purchases, made on the recommendation of the standing Library Committee, included 32 Volumes and 6 Parts of separately-published Works; 24 Volumes of Works published serially; and 7 Sheets of Maps.

A set of the third series of photographs and the corresponding lantern-slides, issued by the Geological Photographs Committee of the British Association, was subscribed for, and is now deposited in the Library.

Great progress has been made during the past year in overtaking the arrears of binding and map-mounting.

The Expenditure incurred in connection with the Library during 1904 was as follows :—

	£	s.	d.
Books, Periodicals, etc. purchased . . . . .	67	8	5
Binding of Books and Mounting of Maps . . . .	139	15	6
Total	<u>£207</u>	<u>3</u>	<u>11</u>

With regard to the progress of the new Card-Catalogue of the Library, upon which he is engaged, Mr. C. Davies Sherborn supplies the following details :—

‘Work on the card-catalogue of the Library progresses favourably. The Annual Lists of Additions have been mounted and indexed, as to subjects and localities, up to and including 1897. There still remains about two years’ labour before current literature will be overtaken and the indexing of the early serials and “Academies” can be commenced, at which time, it is hoped, money will be available for expediting this portion of the work. As each year’s “Additions” demand the use of some 7,500 cards, some idea may be formed of the extent of the Catalogue projected for the convenience of the Fellows.’

#### MUSEUM.

For the purpose of study and comparison, the Collections were visited on 26 occasions during the year, the contents of about 67 drawers being thus examined. Moreover, the permission of the Council having been duly obtained, about 115 specimens were lent during 1904 to various investigators.

No expenditure has been incurred in connection with the Museum during the past year.

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :—

#### I. GOVERNMENT DEPARTMENTS AND OTHER PUBLIC BODIES.

- Alabama.—Geological Survey, University (Ala.).
- American Museum of Natural History. New York.
- Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
- Bavaria.—Königliches Bayerisches Oberbergamt. Munich.
- Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique. Brussels.
- Musée Royal d’Histoire Naturelle. Brussels.
- Berlin.—Königliche Preussische Akademie der Wissenschaften.
- Birmingham, University of.
- Bohemia.—Royal Museum of Natural History. Prague.
- Naturwissenschaftliche Landesdurchforschung. Prague.

- British Columbia.—Department of Mines, Victoria (B.C.).  
 British Guiana.—Department of Mines. Georgetown.  
 British South Africa Company. London.  
 Buenos Aires.—Museo Nacional de Buenos Aires.  
 California University. Berkeley (Cal.).  
 Cambridge (Mass.).—Museum of Comparative Zoology, Harvard College.  
 Canada.—Geological & Natural History Survey. Ottawa.  
 —, High Commissioner for. London.  
 Cape Colony.—Department of Agriculture: Geological Commission. Cape Town.  
 —, South African Museum. Cape Town.  
 Carolina (N.).—Geological Survey. Raleigh (N. Car.).  
 Chicago.—Field' Columbian Museum.  
 Denmark.—Commission for Ledelsen af de Geologiske og Geographiske Undersøgelser i Grönland. Copenhagen.  
 —, Kongelige Danske Videnskabernes Selskab. Copenhagen.  
 Dublin.—Royal Irish Academy.  
 Egypt.—Department of Public Works: Geological Survey. Cairo.  
 Finland.—Finlands Geologiska Undersökning. Helsingfors.  
 France.—Ministère des Travaux Publics. Paris.  
 —, Muséum d'Histoire Naturelle. Paris.  
 Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle an der Saale.  
 Great Britain.—Army Medical Department. London.  
 —, British Museum (Natural History). London.  
 —, Colonial Office. London.  
 —, Geological Survey. London.  
 —, Home Office. London.  
 —, India Office. London.  
 —, Ordnance Survey. Southampton.  
 Holland.—Departement van Kolonien. The Hague.  
 Hull.—Municipal Museum.  
 Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.  
 India.—Geological Survey. Calcutta.  
 —, Surveyor-General's Office. Calcutta.  
 Iowa Geological Survey. Des Moines (Iowa).  
 Ireland.—Department of Agriculture & Technical Instruction. Dublin.  
 Italy.—Reale Comitato Geologico. Rome.  
 Japan.—Earthquake-Investigation Committee. Tokio.  
 —, Geological Survey. Tokio.  
 Jassy, University of.  
 Kansas.—University Geological Survey. Lawrence (Kan.).  
 Kingston (Canada).—Queen's College.  
 London.—City of London College.  
 —, Imperial Institute.  
 —, Royal College of Surgeons.  
 —, University College.  
 Mexico.—Instituto Geologico. Mexico City.  
 Michigan College of Mines. Houghton (Mich.).  
 Milan.—Reale Istituto Lombardo di Scienze & Lettere.  
 Munich.—Königliche Bayerische Akademie der Wissenschaften.  
 Mysore Geological Department. Bangalore.  
 Nancy.—Académie de Stanislas.  
 Natal.—Department of Mines. Pietermaritzburg.  
 —, Geological Survey. Pietermaritzburg.  
 New Jersey.—Geological Survey. Trenton (N.J.).  
 New South Wales, Agent-General for. London.  
 —, Department of Mines & Agriculture. Sydney.  
 —, Geological Survey. Sydney.  
 New York State Museum. Albany (N.Y.).  
 New Zealand.—Department of Mines. Wellington.  
 Nova Scotia.—Department of Mines. Halifax.  
 Ohio.—Geological Survey. Columbus (Ohio).  
 Padua.—Reale Accademia di Scienze, Lettere & Arti.  
 Paris.—Académie des Sciences.  
 Perak Government. Taiping.

- Peru.—Ministerio de Fomento. Lima.  
 Pisa, Royal University of.  
 Portugal.—Comissão dos Trabalhos geologicos. Lisbon.  
 Prussia.—Ministerium für Handel & Gewerbe. Berlin.  
 —. Königliche Preussische Geologische Landesanstalt. Berlin.  
 Queensland, Agent-General for. London.  
 —. Department of Mines. Brisbane.  
 —. Geological Survey. Brisbane.  
 Redruth School of Mines.  
 Rhodesian Museum. Bulawayo.  
 Rio de Janeiro.—Museu Nacional.  
 Rome.—Reale Accademia dei Lincei.  
 Russia.—Comité Géologique. St. Petersburg.  
 —. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.  
 South Australia, Agent-General for. London.  
 —. Geological Survey. Adelaide.  
 Spain.—Comision del Mapa Geológico. Madrid.  
 Stockholm.—Kongliga Svenska Vetenskaps Akademi.  
 Sweden.—Sveriges Geologiska Undersökning. Stockholm.  
 Switzerland.—Geologische Kommission der Schweiz. Berne.  
 Tasmania.—Secretary for Mines. Hobart.  
 Tokio.—Imperial University.  
 —. College of Science.  
 Transvaal.—Geological Survey. Pretoria.  
 —. Mines Department. Pretoria.  
 Turin.—Reale Accademia delle Scienze.  
 United States.—Geological Survey. Washington (D.C.).  
 —. Department of Agriculture. Washington (D.C.).  
 —. National Museum. Washington (D.C.).  
 Upsala, University of.  
 Victoria (Austral.), Agent-General for. London.  
 — (—). Department of Mines. Melbourne.  
 — (—). Geological Survey. Melbourne.  
 Vienna.—Kaiserliche Akademie der Wissenschaften.  
 Washington (D.C.).—Smithsonian Institution.  
 West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).  
 Western Australia, Agent-General for. London.  
 —. Department of Mines. Perth (W.A.).  
 —. Geological Survey. Perth (W.A.).  
 Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).

## II. SOCIETIES AND EDITORS.

- Acireale.—Accademia di Scienze, Lettere & Arti.  
 Adelaide.—Royal Society of South Australia.  
 Agram.—Societas Historico-Naturalis Croatica.  
 Alnwick.—Berwickshire Naturalists' Club.  
 Basel.—Naturforschende Gesellschaft.  
 Bath.—Natural History & Antiquarian Field-Club.  
 Belgrade.—Servian Geological Society.  
 Berlin.—Deutsche Geologische Gesellschaft.  
 —. Gesellschaft Naturforschender Freunde.  
 —. 'Zeitschrift für Praktische Geologie.'  
 Berne.—Schweizerische Naturforschende Gesellschaft.  
 Bishop Auckland.—Weardale Naturalists' Field-Club.  
 Bombay Branch of the Royal Asiatic Society.  
 Bordeaux.—Société Linnéenne.  
 Boston (Mass.) Society of Natural History.  
 —. American Academy of Arts & Sciences.  
 Brooklyn (N.Y.) Institute of Arts & Sciences.  
 Brunswick.—Verein für Naturwissenschaft zu Braunschweig.  
 Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.  
 Budapest.—Földtani Közlöny.  
 Buenos Aires.—Sociedad Científica Argentina.  
 Bulawayo.—Rhodesian Scientific Association.

- Caen.—Société Linnéenne de Normandie.  
 Calcutta.—‘Indian Engineering.’  
 —. Asiatic Society of Bengal.  
 Cambridge Philosophical Society.  
 Cape Town.—South African Association for the Advancement of Science.  
 —. South African Philosophical Society.  
 Cardiff.—South Wales Institute of Engineers.  
 Chicago.—‘Journal of Geology.’  
 Christiania.—‘Nyt Magazin for Naturvidenskaberne.’  
 Colombo.—Ceylon Branch of the Royal Asiatic Society.  
 Colorado Springs.—‘Colorado College Studies.’  
 Córdoba (Argentine Republic).—Academia Nacional de Ciencias.  
 Cracow.—Académie des Sciences (Akademia Umiejetnosci).  
 Croydon Microscopical & Natural History Society.  
 Dorpat.—Naturforschende Gesellschaft.  
 Dresden.—Naturwissenschaftliche Gesellschaft.  
 —. Verein für Erdkunde.  
 Edinburgh.—Royal Scottish Geographical Society.  
 —. Royal Society.  
 Ekaterinburg.—Société Ouralienne d’Amateurs des Sciences Naturelles.  
 Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.  
 Freiburg im Breisgau.—Naturforschende Gesellschaft.  
 Geneva.—Société de Physique & d’Histoire Naturelle.  
 Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.  
 Gloucester.—Cotteswold Naturalists’ Field-Club.  
 Gratz.—Naturwissenschaftlicher Verein für Steiermark.  
 Haarlem.—Société Hollandaise des Sciences.  
 Halifax (N.S.).—Nova Scotian Institute of Science.  
 Hanau.—Wetterauische Gesellschaft für Gesamnte Naturkunde.  
 Havre.—Société Géologique de Normandie.  
 Hertford.—Hertfordshire Natural History Society.  
 Hull Geological Society.  
 Indianapolis.—Indiana Academy of Science.  
 Johannesburg.—Geological Society of South Africa.  
 Kiev.—Société des Naturalistes.  
 Lausanne.—Société Vaudoise des Sciences Naturelles.  
 Lawrence.—‘Kansas University Bulletin.’  
 Leeds Philosophical & Literary Society.  
 —. Yorkshire Geological & Polytechnic Society.  
 Leicester Literary & Philosophical Society.  
 Leipzig.—‘Zeitschrift für Krystallographie & Mineralogie.’  
 Liège.—Société Géologique de Belgique.  
 —. Société Royale des Sciences.  
 Lille.—Société Géologique du Nord.  
 Lima.—‘Revista de Ciencias.’  
 Lisbon.—Sociedade de Geographia.  
 Liverpool Geological Society.  
 London.—‘The Academy.’  
 —. ‘The Athenæum.’  
 —. British Association for the Advancement of Science.  
 —. British Association of Waterworks Engineers.  
 —. ‘The Chemical News.’  
 —. Chemical Society.  
 —. ‘The Colliery-Guardian.’  
 —. East India Association.  
 —. ‘The Geological Magazine.’  
 —. Geologists’ Association.  
 —. Institute of Sanitary Engineers.  
 —. Institution of Civil Engineers.  
 —. Institution of Mining & Metallurgy.  
 —. Iron & Steel Institute.  
 —. ‘The Iron & Steel Trades’ Journal.’  
 —. ‘Knowledge.’  
 —. Linnean Society.  
 —. ‘The London, Edinburgh, & Dublin Philosophical Magazine.’  
 —. Mineralogical Society.  
 —. ‘Nature.’  
 —. Palæontographical Society.



London.—‘The Quarry.’

—Records of the London & West-Country Chamber of Mines.

—Royal Agricultural Society.

—Royal Geographical Society.

—Royal Institution.

—Royal Meteorological Society.

—Royal Microscopical Society.

—Royal Photographic Society.

—Royal Society.

—Society of Arts.

—Society of Biblical Archæology.

—‘The South-Eastern Naturalist’ (S.E. Union of Scientific Societies).

—Victoria Institute.

—‘Water.’

—Zoological Society.

Manchester Geological & Mining Society.

—Literary & Philosophical Society.

Melbourne.—Australasian Institute of Mining Engineers.

—Royal Society of Victoria.

Mexico.—Sociedad Científica ‘Antonio Alzate.’

Moscow.—Société Impériale des Naturalistes.

New Haven (Conn.).—‘The American Journal of Science.’

New York.—Academy of Sciences.

—American Institute of Mining Engineers.

—‘Science.’

Newcastle-upon-Tyne.—Institution of Mining Engineers.

—North-of-England Institute of Mining & Mechanical Engineers.

Northampton.—Northamptonshire Natural History Society.

Ottawa.—Royal Society of Canada.

Paris.—Commission Française des Glaciers.

—Société Française de Minéralogie.

—Société Géologique de France.

—‘Spelunca.’

Penzance.—Royal Geological Society of Cornwall.

Perth.—Perthshire Society of Natural Science.

Philadelphia.—Academy of Natural Sciences.

—American Philosophical Society.

—Wagner Free Institute of Science.

Pisa.—Società Toscana di Scienze Naturali.

Plymouth.—Devonshire Association for the Advancement of Science.

Rennes.—Société Scientifique & Médicale de l’Ouest.

Rochester (N.Y.).—Academy of Science.

—Geological Society of America.

Rome.—Società Geologica Italiana.

Rugby School Natural History Society.

Santiago de Chile.—Sociedad Nacional de Minería.

—Société Scientifique du Chili.

Scranton (Pa.).—‘Mines & Minerals.’

St. John (N.B.).—Natural History Society of New Brunswick.

St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.

Stockholm.—Geologiska Förening.

Stuttgart.—‘Centralblatt für Mineralogie, Geologie & Paläontologie.’

—‘Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.’

—Verein für Vaterländische Naturkunde in Württemberg.

—‘Zeitschrift für Naturwissenschaften.’

Sydney (N.S.W.).—Linnean Society of New South Wales.

—Royal Society of New South Wales.

Toronto.—Canadian Institute.

Toulouse.—Société d’Histoire Naturelle.

Truro.—Royal Institution of Cornwall.

Vienna.—‘Berg- & Hüttenmännisches Jahrbuch.’

—Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.

Washington (D.C.).—Academy of Sciences.

—Biological Society.

Wellington (N.Z.).—New Zealand Institute.

Wiesbaden.—Nassauischer Verein für Naturkunde.

York.—Yorkshire Philosophical Society.

## III. PERSONAL DONORS.

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Hovey, E. O.  
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Hudleston, W. H.  
Hull, E.

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Jukes-Browne, A. J.

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Walther, J.  
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Warren, S. H.  
Washington, H. S.  
Watts, W. W.  
Whitaker, W.  
Wieland, G. R.  
Wilckens, O.  
Woodward, H.  
Woodward, H. B.  
Woolacott, D.  
Wysocki, S.

Zeiller, R.  
Zittel, K. A. von.

COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE  
CLOSE OF THE YEARS 1903 AND 1904.

	Dec. 31st, 1903.	Dec. 31st, 1904.
Compounders .....	287	281
Contributing Fellows.....	930	934
Non-Contributing Fellows..	37	36
	<hr/>	<hr/>
	1254	1251
Foreign Members .....	40	40
Foreign Correspondents....	38	40
	<hr/>	<hr/>
	1332	1331

*Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1903 and 1904.*

Number of Compounders, Contributing and Non-Contributing Fellows, December 31st, 1903 ..	1254
Add Fellows elected during the former year and paid in 1904 .....	13
Add Fellows elected and paid in 1904 .....	31
	<hr/>
	1298
Deduct Compounders deceased.....	13
Contributing Fellows deceased .....	14
Non-Contributing Fellow deceased .....	1
Contributing Fellows resigned .....	13
Contributing Fellows removed .....	6
	<hr/>
	47
	<hr/>
	1251
Number of Foreign Members and Foreign Correspondents, December 31st, 1903 .....	78
Deduct Foreign Members deceased .....	2
Foreign Correspondents deceased ..	1
Foreign Correspondents elected } ..	2
Foreign Members .....	—
	<hr/>
	5
	<hr/>
	73
Add Foreign Members elected .....	2
Foreign Correspondents elected ....	5
	<hr/>
	7
	<hr/>
	80
	<hr/>
	1331

## DECEASED FELLOWS.

*Compounders* (13).

Browne, R. M.	Myers-Beswick, W. B.
Ferguson, W.	Ricketts, Dr. C.
Foster, Sir Clement Le Neve.	Roberts, Dr. I.
Fothergill, Lt.-Col. C. W.	Serocold, C. P.
Francis, Dr. W.	Tomes, R. F.
McMahon, Lt.-General C. A.	Ward, H.
Moore, S. P.	

*Resident and other Contributing Fellows* (14).

Fowler, P.	McDonald, J. A.
Gurney, Rev. H. P.	Pearson, H. W.
Harman, F. E.	Prado, M.
Hawell, Rev. J.	Rutley, F.
Hoskold, H. D.	Swan, R. M. W.
Jackson, W.	Valpy, R. H.
McClean, F.	Wall, P. W.

*Non-contributing Fellow* (1).

Brass, Rev. H.

## DECEASED FOREIGN MEMBERS (2).

Fouqué, Prof. F. A.	Zittel, Prof. K. A. von.
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## DECEASED FOREIGN CORRESPONDENT (1).

Beecher, Prof. C. E.

## FELLOWS RESIGNED (13).

Allhusen, E. L.	May, W.
Ball, W. J.	Moulden, J. C.
Bradley, J. W.	Oliver, T. A.
Clifford, Rev. J.	Smith, F. H.
Ford, H. W.	Spurrell, F. C. J.
Haig, Lt.-Colonel H. de Haga.	Vassall, H.
Hanks, H. G.	

## FELLOWS REMOVED (6).

Bolton, A. J.	Mackenzie, J.
Heath, Rev. A. J.	Monckton, G. F.
Lowles, J. I.	Murray, R. A. F.

*The following Personages were elected Foreign Members during the year 1904:—*

Prof. Joseph Paxson Iddings, of Chicago.  
Dr. Henry Fairfield Osborn, of New York.

*The following Personages were elected Foreign Correspondents during the year 1904:—*

Dr. William Bullock Clark, of Baltimore.  
Dr. Erich Dagobert von Drygalski, of Charlottenburg.  
Prof. Giuseppe de Lorenzo, of Naples.  
The Hon. Frank Springer, of Burlington, U.S.A.  
Dr. Henry S. Washington, of Locust, U.S.A.

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After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to Sir Archibald Geikie and Mr. E. T. Newton, retiring from the office of Vice-President.

That the thanks of the Society be given to Mr. R. S. Herries, retiring from the office of Secretary.

That the thanks of the Society be given to the Rt. Hon. Lord Avebury, Prof. T. T. Groom, Mr. Alfred Harker, Mr. E. T. Newton, and Mr. G. T. Prior, retiring from the Council.

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After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

## OFFICERS AND COUNCIL.—1905.

*PRESIDENT.*

John Edward Marr, Sc.D., F.R.S.

*VICE-PRESIDENTS.*

Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S., F.S.A.

Robert Stansfield Herries, M.A.

Prof. Charles Lapworth, M.Sc., LL.D., F.R.S.

Horace Bolingbroke Woodward, F.R.S.

*SECRETARIES.*

Prof. William Whitehead Watts, M.A., M.Sc., F.R.S.

Prof. Edmund Johnstone Garwood, M.A.

*FOREIGN SECRETARY.*

Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S., F.S.A.

*TREASURER.*

William Thomas Blanford, C.I.E., LL.D., F.R.S.

*COUNCIL.*

Francis Arthur Bather, M.A., D.Sc.

William Thomas Blanford, C.I.E.,  
LL.D., F.R.S.Prof. Thomas George Bonney, Sc.D.,  
LL.D., F.R.S., F.S.A.Sir John Evans, K.C.B., D.C.L.,  
LL.D., F.R.S., F.S.A.Prof. Edmund Johnstone Garwood,  
M.A.Sir Archibald Geikie, Sc.D., D.C.L.,  
LL.D., Sec.R.S.

Robert Stansfield Herries, M.A.

Prof. John W. Judd, C.B., LL.D.,  
F.R.S.

Prof. Percy Fry Kendall.

Philip Lake, M.A.

Prof. Charles Lapworth, M.Sc.,  
LL.D., F.R.S.

Richard Lydekker, B.A., F.R.S.

Bedford McNeill, Assoc.R.S.M.

John Edward Marr, Sc.D., F.R.S.

Prof. Henry Alexander Miers, M.A.,  
F.R.S.Horace Woollaston Monckton,  
F.L.S.

Frederick William Rudler, I.S.O.

Leonard James Spencer, M.A.

Aubrey Strahan, M.A., F.R.S.

Charles Fox Strangways.

Prof. William Whitehead Watts,  
M.A., M.Sc., F.R.S.The Rev. Henry Hoyte Winwood,  
M.A.Horace Bolingbroke Woodward,  
F.R.S.

# LIST OF THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1904.

Date of  
Election.

- 1874. Prof. Albert Jean Gaudry, *Paris*.
- 1877. Prof. Eduard Suess, *Vienna*.
- 1880. Prof. Gustave Dewalque, *Liège*.
- 1880. Geheimrath Prof. Ferdinand Zirkel, *Leipzig*.
- 1884. Commendatore Prof. Giovanni Capellini, *Bologna*.
- 1885. Prof. Jules Gosselet, *Lille*.
- 1886. Prof. Gustav Tschermak, *Vienna*.
- 1888. Prof. Eugène Renevier, *Lausanne*.
- 1888. Baron Ferdinand von Richthofen, *Berlin*.
- 1890. Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg*.
- 1891. Prof. Charles Barrois, *Lille*.
- 1893. Prof. Waldemar Christofer Brøgger, *Christiania*.
- 1893. M. Auguste Michel-Lévy, *Paris*.
- 1893. Dr. Edmund Mojsisovics von Mojsvár, *Vienna*.
- 1893. Prof. Alfred Gabriel Nathorst, *Stockholm*.
- 1894. Prof. George J. Brush, *New Haven, Conn. (U.S.A.)*.
- 1894. Prof. Edward Salisbury Dana, *New Haven, Conn. (U.S.A.)*.
- 1895. Prof. Grove Karl Gilbert, *Washington, D.C. (U.S.A.)*.
- 1895. Dr. Friedrich Schmidt, *St. Petersburg*.
- 1896. Prof. Albert Heim, *Zürich*.
- 1897. M. Édouard Dupont, *Brussels*.
- 1897. Dr. Anton Fritsch, *Prague*.
- 1897. Prof. Albert de Lapparent, *Paris*.
- 1897. Dr. Hans Reusch, *Christiania*.
- 1898. Geheimrath Prof. Hermann Credner, *Leipzig*.
- 1898. Mr. Charles Doolittle Walcott, *Washington, D.C. (U.S.A.)*.
- 1899. Prof. Marcel Bertrand, *Paris*.
- 1899. Senhor Joaquim Felipe Nery Delgado, *Lisbon*.
- 1899. Prof. Emmanuel Kayser, *Marburg*.
- 1899. M. Ernest Van den Broeck, *Brussels*.
- 1899. Dr. Charles Abiathar White, *Washington, D.C. (U.S.A.)*.
- 1900. M. Gustave F. Dollfus, *Paris*.
- 1900. Prof. Paul Groth, *Munich*.
- 1900. Dr. Sven Leonhard Tørnquist, *Lund*.
- 1901. M. Alexander Petrovich Karpinsky, *St. Petersburg*.
- 1901. Prof. Alfred Lacroix, *Paris*.
- 1903. Prof. Albrecht Penck, *Vienna*.
- 1903. Prof. Anton Koch, *Budapest*.
- 1904. Prof. Joseph Paxson Iddings, *Chicago (U.S.A.)*.
- 1904. Prof. Henry Fairfield Osborn, *New York (U.S.A.)*.

# LIST OF THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1904.

Date of  
Election.

- 1866. Prof. Victor Raulin, *Montfaucon d'Argonne*. (*Deceased.*)
  - 1874. Prof. Igino Cocchi, *Florence*.
  - 1879. Dr. Émile Sauvage, *Boulogne-sur-Mer*.
  - 1889. Dr. Rogier Diederik Marius Verbeek, *The Hague*.
  - 1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen*.
  - 1892. Prof. Johann Lehmann, *Kiel*.
  - 1893. Prof. Aléxis P. Pavlow, *Moscow*.
  - 1893. M. Ed. Rigaux, *Boulogne-sur-Mer*.
  - 1894. Prof. Joseph Paxson Iddings, *Chicago, Ill. (U.S.A.)*. (*Elected Foreign Member.*)
  - 1894. M. Perceval de Loriol-Lefort, *Campagne Frontenex, near Geneva*.
  - 1894. Dr. Francisco P. Moreno, *La Plata*.
  - 1894. Prof. August Rothpletz, *Munich*.
  - 1894. Prof. J. H. L. Vogt, *Christiania*.
  - 1895. Prof. Constantin de Kroustchoff, *St. Petersburg*.
  - 1896. Prof. Samuel L. Penfield, *New Haven, Conn. (U.S.A.)*.
  - 1896. Prof. Johannes Walther, *Jena*.
  - 1897. Dr. Louis Dollo, *Brussels*.
  - 1897. M. Emmanuel de Margerie, *Paris*.
  - 1897. Prof. Count H. zu Solms-Laubach, *Strasburg*.
  - 1898. Dr. Marcellin Boule, *Paris*.
  - 1898. Dr. W. H. Dall, *Washington, D.C. (U.S.A.)*.
  - 1899. Dr. Gerhard Holm, *Stockholm*.
  - 1899. Prof. Theodor Liebisch, *Göttingen*.
  - 1899. Prof. Franz Lœwinson-Lessing, *St. Petersburg*.
  - 1899. M. Michel F. Murlon, *Brussels*.
  - 1899. Prof. Henry Fairfield Osborn, *New York (U.S.A.)*. (*Elected Foreign Member.*)
  - 1899. Prof. Gregorio Stefanescu, *Bucharest*.
  - 1899. Prof. René Zeiller, *Paris*.
  - 1900. Commendatore Prof. Arturo Issel, *Genoa*.
  - 1900. Prof. Ernst Koken, *Tübingen*.
  - 1900. Prof. Federico Sacco, *Turin*.
  - 1901. Prof. Friedrich Johann Becke, *Vienna*.
  - 1902. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill. (U.S.A.)*.
  - 1902. Dr. Thorvaldr Thoroddsen, *Copenhagen*.
  - 1902. Prof. Samuel Wendell Williston, *Chicago, Ill. (U.S.A.)*.
  - 1903. Geheimer Bergrath Prof. Carl Klein, *Berlin*.
  - 1903. Dr. Emil Ernst August Tietze, *Vienna*.
  - 1904. Dr. William Bullock Clark, *Baltimore (U.S.A.)*.
  - 1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg*.
  - 1904. Prof. Giuseppe de Lorenzo, *Naples*.
  - 1904. The Hon. Frank Springer, *Burlington, Iowa (U.S.A.)*.
  - 1904. Dr. Henry S. Washington, *Locust, N.J. (U.S.A.)*.
-



# AWARDS OF THE WOLLASTON MEDAL

## UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,—‘such individual not being a Member of the Council.’

- |                                     |                                     |
|-------------------------------------|-------------------------------------|
| 1831. Mr. William Smith.            | 1869. Dr. Henry C. Sorby.           |
| 1835. Dr. G. A. Mantell.            | 1870. Prof. G. P. Deshayes.         |
| 1836. M. Louis Agassiz.             | 1871. Sir Andrew Ramsay.            |
| 1837. { Capt. T. P. Cautley.        | 1872. Prof. James D. Dana.          |
| { Dr. H. Falconer.                  | 1873. Sir P. de M. Grey Egerton.    |
| 1838. Sir Richard Owen.             | 1874. Prof. Oswald Heer.            |
| 1839. Prof. C. G. Ehrenberg.        | 1875. Prof. L. G. de Koninck.       |
| 1840. Prof. A. H. Dumont.           | 1876. Prof. Thomas H. Huxley.       |
| 1841. M. Adolphe T. Brongniart.     | 1877. Mr. Robert Mallet.            |
| 1842. Baron Leopold von Buch.       | 1878. Dr. Thomas Wright.            |
| 1843. { M. Élie de Beaumont.        | 1879. Prof. Bernhard Studer.        |
| { M. P. A. Dufrénoy.                | 1880. Prof. Auguste Daubrée.        |
| 1844. The Rev. W. D. Conybeare.     | 1881. Prof. P. Martin Duncan.       |
| 1845. Prof. John Phillips.          | 1882. Dr. Franz Ritter von Hauer.   |
| 1846. Mr. William Lonsdale.         | 1883. Dr. William Thomas            |
| 1847. Dr. Ami Boué.                 | Blanford.                           |
| 1848. The Very Rev. W. Buckland.    | 1884. Prof. Albert Jean Gaudry.     |
| 1849. Sir Joseph Prestwich.         | 1885. Mr. George Busk.              |
| 1850. Mr. William Hopkins.          | 1886. Prof. A. L. O. Des Cloizeaux. |
| 1851. The Rev. Prof. A. Sedgwick.   | 1887. Mr. John Whitaker Hulke.      |
| 1852. Dr. W. H. Fitton.             | 1888. Mr. Henry B. Medlicott.       |
| 1853. { M. le Vicomte A. d'Archiac. | 1889. Prof. Thomas George Bonney.   |
| { M. E. de Verneuil.                | 1890. Prof. W. C. Williamson.       |
| 1854. Sir Richard Griffith.         | 1891. Prof. John Wesley Judd.       |
| 1855. Sir Henry De la Beche.        | 1892. Baron Ferdinand von           |
| 1856. Sir William Logan.            | Richthofen.                         |
| 1857. M. Joachim Barrande.          | 1893. Prof. Nevil Story Maskelyne.  |
| 1858. { Herr Hermann von Meyer.     | 1894. Prof. Karl Alfred von Zittel. |
| { Prof. James Hall.                 | 1895. Sir Archibald Geikie.         |
| 1859. Mr. Charles Darwin.           | 1896. Prof. Eduard Suess.           |
| 1860. Mr. Searles V. Wood.          | 1897. Mr. Wilfrid H. Hudleston.     |
| 1861. Prof. Dr. H. G. Bronn.        | 1898. Prof. Ferdinand Zirkel.       |
| 1862. Mr. R. A. C. Godwin-Austen.   | 1899. Prof. Charles Lapworth.       |
| 1863. Prof. Gustav Bischof.         | 1900. Prof. Grove Karl Gilbert.     |
| 1864. Sir Roderick Murchison.       | 1901. Prof. Charles Barrois.        |
| 1865. Dr. Thomas Davidson.          | 1902. Dr. Friedrich Schmidt.        |
| 1866. Sir Charles Lyell.            | 1903. Prof. Heinrich Rosenbusch.    |
| 1867. Mr. G. Poulett Scrope.        | 1904. Prof. Albert Heim.            |
| 1868. Prof. Carl F. Naumann.        | 1905. Dr. J. J. Harris Teall.       |

## A W A R D S

## OF THE

## BALANCE OF THE PROCEEDS OF THE WOLLASTON

## 'DONATION-FUND.'

- |                                    |                                     |
|------------------------------------|-------------------------------------|
| 1831. Mr. William Smith.           | 1869. Mr. William Carruthers.       |
| 1833. Mr. William Lonsdale.        | 1870. M. Marie Rouault.             |
| 1834. M. Louis Agassiz.            | 1871. Mr. Robert Etheridge.         |
| 1835. Dr. G. A. Mantell.           | 1872. Dr. James Croll.              |
| 1836. Prof. G. P. Deshayes.        | 1873. Prof. John Wesley Judd.       |
| 1838. Sir Richard Owen.            | 1874. Dr. Henri Nyst.               |
| 1839. Prof. C. G. Ehrenberg.       | 1875. Prof. L. C. Miall.            |
| 1840. Mr. J. De Carle Sowerby.     | 1876. Prof. Giuseppe Seguenza.      |
| 1841. Prof. Edward Forbes.         | 1877. Mr. Robert Etheridge, Jun.    |
| 1842. Prof. John Morris.           | 1878. Prof. William Johnson Sollas. |
| 1843. Prof. John Morris.           | 1879. Mr. Samuel Allport.           |
| 1844. Mr. William Lonsdale.        | 1880. Mr. Thomas Davies.            |
| 1845. Mr. Geddes Bain.             | 1881. Dr. Ramsay Heatley Traquair.  |
| 1846. Mr. William Lonsdale.        | 1882. Dr. George Jennings Hinde.    |
| 1847. M. Alcide d'Orbigny.         | 1883. Prof. John Milne.             |
| 1848. } Cape-of-Good-Hope Fossils. | 1884. Mr. Edwin Tulley Newton.      |
| } M. Alcide d'Orbigny.             | 1885. Dr. Charles Callaway.         |
| 1849. Mr. William Lonsdale.        | 1886. Mr. J. Starkie Gardner.       |
| 1850. Prof. John Morris.           | 1887. Mr. Benjamin Neeve Peach.     |
| 1851. M. Joachim Barrande.         | 1888. Dr. John Horne.               |
| 1852. Prof. John Morris.           | 1889. Dr. Arthur Smith Woodward.    |
| 1853. Prof. L. G. de Koninck.      | 1890. Mr. William A. E. Ussher.     |
| 1854. Dr. Samuel P. Woodward.      | 1891. Mr. Richard Lydekker.         |
| 1855. Drs. G. and F. Sandberger.   | 1892. Mr. Orville Adelbert Derby.   |
| 1856. Prof. G. P. Deshayes.        | 1893. Mr. John George Goodchild.    |
| 1857. Dr. Samuel P. Woodward.      | 1894. Mr. Aubrey Strahan.           |
| 1858. Prof. James Hall.            | 1895. Prof. William W. Watts.       |
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| 1861. Prof. Auguste Daubrée.       | 1899. Prof. John B. Harrison.       |
| 1862. Prof. Oswald Heer.           | 1900. Mr. George Thurland Prior.    |
| 1863. Prof. Ferdinand Senft.       | 1901. Mr. Arthur Walton Rowe.       |
| 1864. Prof. G. P. Deshayes.        | 1902. Mr. Leonard James Spencer.    |
| 1865. Mr. J. W. Salter.            | 1903. Mr. L. L. Belinfante.         |
| 1866. Dr. Henry Woodward.          | 1904. Miss Ethel M. R. Wood.        |
| 1867. Mr. W. H. Baily.             | 1905. Mr. H. H. Arnold-Bemrose.     |
| 1868. M. J. Bosquet.               |                                     |

## AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

‘MURCHISON GEOLOGICAL FUND,’

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, BART., F.R.S., F.G.S.

‘To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.’

- |                                  |                                 |
|----------------------------------|---------------------------------|
| 1873. Mr. William Davies.        | 1890. Prof. Edward Hull.        |
| 1874. Dr. J. J. Bigsby.          | 1891. Prof. Waldemar C. Brögge  |
| 1875. Mr. W. J. Henwood.         | 1892. Prof. A. H. Green.        |
| 1876. Mr. Alfred R. C. Selwyn.   | 1893. The Rev. Osmond Fisher.   |
| 1877. The Rev. W. B. Clarke.     | 1894. Mr. William T. Aveline.   |
| 1878. Prof. Hanns Bruno Geinitz. | 1895. Prof. Gustaf Lindström.   |
| 1879. Sir Frederick M'Coy.       | 1896. Mr. T. Mellard Reade.     |
| 1880. Mr. Robert Etheridge.      | 1897. Mr. Horace B. Woodward.   |
| 1881. Sir Archibald Geikie.      | 1898. Mr. Thomas F. Jamieson.   |
| 1882. Prof. Jules Gosselet.      | 1899. { Mr. Benjamin N. Peach.  |
| 1883. Prof. H. R. Goëppert.      | { Dr. John Horne.               |
| 1884. Dr. Henry Woodward.        | 1900. Baron A. E. Nordenskiöld. |
| 1885. Dr. Ferdinand von Römer.   | 1901. Mr. A. J. Jukes-Browne.   |
| 1886. Mr. William Whitaker.      | 1902. Mr. Frederic W. Harmer.   |
| 1887. The Rev. Peter B. Brodie.  | 1903. Dr. Charles Callaway.     |
| 1888. Prof. J. S. Newberry.      | 1904. Prof. George A. Lebour.   |
| 1889. Prof. James Geikie.        | 1905. Mr. Edward John Dunn.     |

## A W A R D S

OF THE

BALANCE OF THE PROCEEDS OF THE

‘MURCHISON GEOLOGICAL FUND.’

1873. Prof. Oswald Heer.	1889. Prof. Grenville A. J. Cole.
1874. Mr. Alfred Bell.	1890. Mr. Edward B. Wethered.
1874. Prof. Ralph Tate.	1891. The Rev. Richard Baron.
1875. Prof. H. Govier Seeley.	1892. Mr. Beeby Thompson.
1876. Dr. James Croll.	1893. Mr. Griffith J. Williams.
1877. The Rev. John F. Blake.	1894. Mr. George Barrow.
1878. Prof. Charles Lapworth.	1895. Mr. Albert Charles Seward.
1879. Mr. James Walker Kirkby.	1896. Mr. Philip Lake.
1880. Mr. Robert Etheridge.	1897. Mr. Sydney S. Buckman.
1881. Mr. Frank Rutley.	1898. Miss Jane Donald.
1882. Prof. Thomas Rupert Jones.	1899. Mr. James Bennie.
1883. Dr. John Young.	1900. Mr. A. Vaughan Jennings.
1884. Mr. Martin Simpson.	1901. Mr. Thomas S. Hall.
1885. Mr. Horace B. Woodward.	1902. Mr. Thomas H. Holland.
1886. Mr. Clement Reid.	1903. Mrs. Elizabeth Gray.
1887. Mr. Robert Kidston.	1904. Dr. Arthur Hutchinson.
1888. Mr. Edward Wilson.	1905. Mr. Herbert Lister Bowman.

## AWARDS OF THE PROCEEDS

OF THE

‘DANIEL-PIDGEON FUND,’

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE  
WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

‘An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.’

1903. Prof. Ernest Willington Skeats.

1904. Mr. Linsdall Richardson.

# AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

‘LYELL GEOLOGICAL FUND,’

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal ‘to be cast in bronze and to be given annually’ (or from time to time) ‘as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,’—‘not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.’

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to ‘each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.’

- |                                  |                                      |
|----------------------------------|--------------------------------------|
| 1876. Prof. John Morris.         | 1892. Mr. George H. Morton.          |
| 1877. Sir James Hector.          | 1893. Mr. Edwin Tulley Newton.       |
| 1878. Mr. George Busk.           | 1894. Prof. John Milne.              |
| 1879. Prof. Edmond Hébert.       | 1895. The Rev. John F. Blake.        |
| 1880. Sir John Evans.            | 1896. Dr. Arthur Smith Woodward.     |
| 1881. Sir J. William Dawson.     | 1897. Dr. George Jennings Hinde.     |
| 1882. Dr. J. Lycett.             | 1898. Prof. Wilhelm Waagen.          |
| 1883. Dr. W. B. Carpenter.       | 1899. Lt.-Gen. C. A. McMahon.        |
| 1884. Dr. Joseph Leidy.          | 1900. Dr. John Edward Marr.          |
| 1885. Prof. H. Govier Seeley.    | 1901. Dr. Ramsay Heatley Traquair.   |
| 1886. Mr. William Pengelly.      | 1902. { Prof. Anton Fritsch.         |
| 1887. Mr. Samuel Allport.        | { Mr. Richard Lydekker.              |
| 1888. Prof. Henry A. Nicholson.  | 1903. Mr. Frederick William Rudler.  |
| 1889. Prof. W. Boyd Dawkins.     | 1904. Prof. Alfred Gabriel Nathorst. |
| 1890. Prof. Thomas Rupert Jones. | 1905. Dr. Hans Reusch.               |
| 1891. Prof. T. McKenny Hughes.   |                                      |

A W A R D S  
OF THE  
BALANCE OF THE PROCEEDS OF THE  
'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.	1893. Miss Catherine A. Raisin.
1877. Mr. William Pengelly.	1893. Mr. Alfred N. Leeds.
1878. Prof. Wilhelm Waagen.	1894. Mr. William Hill.
1879. Prof. Henry A. Nicholson.	1895. Prof. Percy Fry Kendall.
1879. Dr. Henry Woodward.	1895. Mr. Benjamin Harrison.
1880. Prof. F. A. von Quenstedt.	1896. Dr. William F. Hume.
1881. Prof. Anton Fritsch.	1896. Dr. Charles W. Andrews.
1881. Mr. G. R. Vine.	1897. Mr. W. J. Lewis Abbott.
1882. The Rev. Norman Glass.	1897. Mr. Joseph Lomas.
1882. Prof. Charles Lapworth.	1898. Mr. William H. Shrubsole.
1883. Mr. P. H. Carpenter.	1898. Mr. Henry Woods.
1883. M. Ed. Rigaux.	1899. Mr. Frederick Chapman.
1884. Prof. Charles Lapworth.	1899. Mr. John Ward.
1885. Mr. Alfred J. Jukes-Browne.	1900. Miss Gertrude L. Elles.
1886. Mr. David Mackintosh.	1901. Dr. John William Evans.
1887. The Rev. Osmond Fisher.	1901. Mr. Alexander McHenry.
1888. Dr. Arthur H. Foord.	1902. Dr. Wheelton Hind.
1888. Mr. Thomas Roberts.	1903. Mr. Sydney S. Buckman.
1889. M. Louis Dollo.	1903. Mr. George Edward Dibley.
1890. Mr. Charles Davies Sherborn.	1904. Dr. Charles Alfred Matley.
1891. Dr. C. I. Forsyth Major.	1904. Prof. Sidney Hugh Reynolds.
1891. Mr. George W. Lamplugh.	1905. Mr. E. A. Newell Arber.
1892. Prof. John Walter Gregory.	1905. Mr. Walcot Gibson.
1892. Mr. Edwin A. Walford.	

AWARD OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.

## AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel Charles Marsh.	1893. Prof. William Johnson Sollas.
1879. Prof. Edward Drinker Cope.	1895. Mr. Charles D. Walcott.
1881. Prof. Charles Barrois.	1897. Mr. Clement Reid.
1883. Dr. Henry Hicks.	1899. Prof. T. W. E. David.
1885. Prof. Alphonse Renard.	1901. Mr. George W. Lamplugh.
1887. Prof. Charles Lapworth.	1903. Dr. Henry M. Ami.
1889. Dr. J. J. Harris Teall.	1905. Prof. John Walter Gregory.
1891. Dr. George Mercer Dawson.	

## AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of Microscope.	1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1881. Purchase of Microscopé - Lamps.	1894. Dr. Charles Davison.
1882. Baron C. von Ettingshausen.	1896. Mr. Joseph Wright.
1884. Dr. James Croll.	1896. Mr. John Storrie.
1884. Prof. Leo Lesquereux.	1898. Mr. Edward Greenly.
1886. Dr. H. J. Johnston-Lavis.	1900. Mr. George C. Crick.
1888. Museum.	1900. Prof. Theodore T. Groom.
1890. Mr. W. Jerome Harrison.	1902. Mr. William M. Hutchings.
1892. Prof. Charles Mayer-Eymar.	1904. Mr. Hugh J. Ll. Beadnell.

*Estimates for*

## INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions .....				140	0	0
Due for Arrears of Admission-Fees .....	94	10	0			
Admission-Fees, 1905 .....	190	0	0			
				284	10	0
Arrears of Annual Contributions .....	175	0	0			
Annual Contributions, 1905, from Resident and Non-Resident Fellows .....	1770	0	0			
Annual Contributions in advance .....	50	0	0			
				1995	0	0
Sale of Quarterly Journal, including Longmans' Account .....				160	0	0
Sale of Transactions, General Index, Library- Catalogue, Museum - Catalogue, Hutton's 'Theory of the Earth' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows .....				5	10	0
Dividends on £2500 India 3 per cent. Stock ..	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Pre- ference-Stock .....	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference-Stock .....	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference-Stock .....	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference-Stock .....	51	16	0			
Dividends on £267 6s. 7d. Natal 3 per cent. Stock ..	8	0	0			
				351	16	0

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£2936 16 0



*the Year 1905.*

EXPENDITURE ESTIMATED.

[illegible]

W. T. BLANFORD, *Treasurer.*

January 20th, 1905.

*Income and Expenditure during the*

## RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at						
January 1st, 1904 .....	176	12	9			
„ Balance in the hands of the Clerk at						
January 1st, 1904 .....	15	14	2			
				192	6	11
„ Compositions .....				238	14	0
„ Admission-Fees:						
Arrears .....	75	12	0			
Current .....	189	0	0			
				264	12	0
„ Arrears of Annual Contributions ....	142	16	0			
„ Annual Contributions for 1904:—						
Resident Fellows .....	1721	9	6			
Non-Resident Fellows .....	11	0	6			
„ Annual Contributions in advance ....	44	2	0			
				1919	8	0
„ Publications :						
Sale of Quarterly Journal: *						
„ Vols. i to lix .....	93	14	0			
„ Vol. lx .....	67	18	2			
				161	12	2
„ Record of Geological Literature ...	2	14	0			
„ List of Fellows .....	8	0				
„ Transactions .....	15	0				
„ Museum-Catalogue.....	5	0				
„ Library-Catalogue .....	11	0				
„ Ormerod's Index .....	3	6				
„ General Index to the Quarterly						
Journal, vols. i to l .....	1	0	8			
„ Hutton's 'Theory of the Earth,'						
vol. iii .....	12	0				
„ Hochstetter's 'New Zealand' .....	8	5				
				6	17	7
„ Repayment of Income Tax (3 years) .....	58	8	4			
„ Prestwich Trust-Fund, part repayment of advance						
for Die of Medal .....	10	0	0			
„ Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock....	71	8	1			
£300 London, Brighton, & South						
Coast Railway 5 per cent.						
Consolidated Preference-						
Stock .....	14	6	0			
£2250 London & North-Western						
Railway 4 per cent. Pre-						
ference-Stock .....	85	15	7			
£2800 London & South-Western						
Railway 4 per cent. Pre-						
ference-Stock .....	106	15	0			
£2072 Midland Railway 2½ per						
cent. Perpetual Preference-						
Stock .....	49	7	5			
£267 6s. 7d. Natal 3 per cent. Stock	7	12	8			
				335	4	9
* Due from Messrs. Longmans & Co., in addition				£3187	3	9
to the above, on Journal-Sales .....	£70	10	9			

*Year ended December 31st, 1904.*

PAYMENTS.

By House-Expenditure:	£	s.	d.	£	s.	d.
Taxes .....		15	0			
Insurance .....	15	0	0			
Electric Lighting and Maintenance .....	50	17	2			
Gas .....	9	2	11			
Fuel .....	35	18	6			
Furniture and Repairs .....	23	4	3			
House-Repairs and Maintenance .....	36	13	0			
Annual Cleaning .....	12	0	0			
Tea at Meetings .....	18	14	2			
Washing and Sundry Expenses .....	35	5	2			
				237	10	2
„ Salaries and Wages :						
Assistant-Secretary .....	350	0	0			
„ half Premium Life-Insurance...	10	15	0			
Assistant-Librarian .....	150	0	0			
Assistant-Clerk .....	150	0	0			
Junior Assistant .....	52	0	0			
House-Porter and Upper Housemaid .....	100	11	6			
Under Housemaid .....	49	1	6			
Charwoman and Occasional Assistance .....	9	7	0			
Accountants' Fee .....	10	10	0			
Do. Commission on Income-Tax recovered...	4	12	7			
				886	17	7
„ Office-Expenditure :						
Stationery .....	31	11	5			
Miscellaneous Printing, etc.....	37	16	10			
Postages and Sundry Expenses .....	79	19	8			
				149	7	11
„ International Catalogue of Scientific Literature ..		60	0	0		
„ Library (Books and Binding) .....		207	3	11		
„ Publications :						
Quarterly Journal, Vol. l-lix, Commission on Sale thereof .....	8	4	6			
Quarterly Journal, Vol. lx, Commission on Sale thereof .....	5	6	6			
Paper, Printing, and Illustrations .....	737	8	10			
Postage on Journal, Addressing, etc. ....	78	10	5			
Abstracts, including Postage .....	108	10	7			
Record of Geological Literature .....	150	7	1			
List of Fellows .....	36	18	8			
Library-Catalogue .....	111	10	0			
				1236	16	7
„ Balance in the hands of the Bankers at December 31st, 1904 .....	395	9	11			
„ Balance in the hands of the Clerk at December 31st, 1904 .....	13	17	8			
				409	7	7

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

H. BAUERMAN,  
HORACE W. MONCKTON, } *Auditors.* £3187 3 9

W. T. BLANFORD, *Treasurer.*

*Statement of Trust-Funds: December 31st, 1904.*

*'WOLLASTON DONATION-FUND.' TRUST-ACCOUNT.*

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
To Balance at the Bankers' at January 1st, 1904 .....	30 8 10	By Award to Miss E. M. R. Wood, and Medal .....	34 6 10
" Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock .....	30 12 10	" Balance at the Bankers', December 31st, 1904 .....	32 2 6
" Repayment of Income-Tax (3 years) .....	5 7 8		
	<u>£66 9 4</u>		<u>£66 9 4</u>

*'MURCHISON GEOLOGICAL FUND.' TRUST-ACCOUNT.*

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
To Balance at the Bankers' at January 1st, 1904 .....	18 18 6	By Award to Prof. G. A. Lebour .....	10 10 0
" Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture-Stock .....	38 2 10	" Cost of Medal .....	17 0
" Repayment of Income-Tax (3 years) .....	6 14 2	" Award to Dr. A. Hutchinson .....	31 7 6
	<u>£63 15 6</u>	" Balance at the Bankers', December 31st, 1904 .....	21 1 0
			<u>£63 15 6</u>

*'LYELL GEOLOGICAL FUND.' TRUST-ACCOUNT.*

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
To Balance at the Bankers' at January 1st, 1904 .....	50 1 2	By Award to Prof. A. G. Nathorst .....	25 0 0
" Dividends (less Income-Tax) on the Fund invested in £2010 1s. 0d. Metropolitan 3½ per cent. Stock .....	66 19 8	" Cost of Medal .....	1 1 0
" Repayment of Income-Tax (3 years) .....	11 14 0	" Award to Prof. S. H. Reynolds .....	24 12 9
		" Dr. C. A. Matley .....	24 12 9
		" Balance at the Bankers', December 31st, 1904 .....	53 8 4
	<u>£128 14 10</u>		<u>£128 14 10</u>

*'BARLOW-JAMESON FUND.' TRUST-ACCOUNT.*

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
To Balance at the Bankers' at January 1st, 1904 .....	21 9 0	By Award to Mr. H. J. Ll. Beadnell .....	21 0 0
" Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock .....	13 7 8	" Balance at the Bankers', December 31st, 1904 .....	16 3 8
" Repayment of Income-Tax (3 years) .....	2 7 0		

To Balance at the Bankers' at January 1st, 1904 .....	3 0 1	By Balance at the Bankers', December 31st, 1904 .....	10 1 0
" Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock .....	5 19 11		
" Repayment of Income-Tax (3 years) .....	1 1 0		
	<u>£10 1 0</u>		<u>£10 1 0</u>

**'GEOLOGICAL RELIEF-FUND.' TRUST-ACCOUNT.**

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
To Balance at the Bankers' at January 1st, 1904 .....	13 14 0	By Balance at the Bankers', December 31st, 1904 .....	18 7 5
" Dividends (less Income-Tax) on the Fund invested in £139 3s. 7d. India 3 per cent. Stock .....	3 19 6		
" Repayment of Income-Tax (3 years) .....	13 11		
	<u>£18 7 5</u>		<u>£18 7 5</u>

**'PRESTWICH TRUST-FUND.' TRUST-ACCOUNT.**

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
To Balance at the Bankers' at January 1st, 1904 .....	3 16 4	By Part Cost of Die .....	10 0 0
" Dividends (less Income-Tax) on the Fund invested in £591 1s. 4d. India 3 per cent. Stock .....	16 17 9	" Purchase of £96 7s. 3d. India 3 per cent. Stock .....	91 8 7
" Repayment of Income-Tax (3 years) .....	2 19 0	" Balance at the Bankers', December 31st, 1904 .....	13 13 1
" Cash received from Messrs. Flower & Flower, further on account of Legacy from the late Sir Joseph Prestwich .....	91 8 7		
	<u>£115 1 8</u>		<u>£115 1 8</u>

**'DANIEL-PIDGEON FUND.' TRUST-ACCOUNT.**

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
To Balance at the Bankers' at January 1st, 1904 .....	14 11 8	By Award to Mr. L. Richardson .....	31 1 6
" Dividends (less Income-Tax) on the Fund invested in £1019 1s. 2d. Bristol Corporation 3 per cent. Stock .....	29 2 1	" Balance at the Bankers', December 31st, 1904 .....	15 18 5
" Repayment of Income-Tax (2 years) .....	3 6 2		
	<u>£46 19 11</u>		<u>£46 19 11</u>

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

W. T. BLANFORD, *Treasurer.*  
January 20th, 1905.

H. BAUERMAN,  
HORACE W. MONCKTON, } *Auditors.*



*Statement of Trust-Funds : December 31st, 1904.*

**'WOLLASTON DONATION-FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904 .....	30	8 10	By Award to Miss E. M. R. Wood, and Medal .....	34	6 10
„ Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock .....	30	12 10	„ Balance at the Bankers', December 31st, 1904 .....	32	2 6
„ Repayment of Income-Tax (3 years) .....	5	7 8			
	£66	9 4		£66	9 4

**'MURCHISON GEOLOGICAL FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904 .....	18	18 6	By Award to Prof. G. A. Lebour .....	10	10 0
„ Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture-Stock .....	38	2 10	„ Cost of Medal .....		17 0
„ Repayment of Income-Tax (3 years) .....	6	14 2	„ Award to Dr. A. Hutchinson .....	31	7 6
	£63	15 6	„ Balance at the Bankers', December 31st, 1904 .....	21	1 0
				£63	15 6

**'LYELL GEOLOGICAL FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904 .....	50	1 2	By Award to Prof. A. G. Nathorst .....	25	0 0
„ Dividends (less Income-Tax) on the Fund invested in £2010 1s. 0d. Metropolitan 3½ per cent. Stock .....	66	19 8	„ Cost of Medal .....	1	1 0
„ Repayment of Income-Tax (3 years) .....	11	14 0	„ Award to Prof. S. H. Reynolds .....	24	12 9
	£128	14 10	„ „ Dr. C. A. Matley .....	24	12 9
			„ Balance at the Bankers', December 31st, 1904 .....	53	8 4
				£128	14 10

**'BARLOW-JAMESON FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904 .....	21	9 0	By Award to Mr. H. J. L. Eendell .....	21	0 0
„ Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock .....	13	7 8	„ Balance at the Bankers', December 31st, 1904 .....	16	3 8
„ Repayment of Income-Tax (3 years) .....	2	7 0			
	£37	3 8		£37	3 8

**'BIGSBY FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904 .....	3	0 1	By Balance at the Bankers', December 31st, 1904 .....	10	1 0
„ Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock .....	5	19 11			
„ Repayment of Income-Tax (3 years) .....	1	1 0			
	£10	1 0		£10	1 0

**'GEOLOGICAL RELIEF-FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904 .....	13	14 0	By Balance at the Bankers', December 31st, 1904 .....	18	7 5
„ Dividends (less Income-Tax) on the Fund invested in £139 3s. 7d. India 3 per cent. Stock .....	3	19 6			
„ Repayment of Income-Tax (3 years) .....		13 11			
	£18	7 5		£18	7 5

**'PRESTWICH TRUST-FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904 .....	3	16 4	By Part Cost of Die .....	10	0 0
„ Dividends (less Income-Tax) on the Fund invested in £591 1s. 4d. India 3 per cent. Stock .....	16	17 9	„ Purchase of £96 7s. 3d. India 3 per cent. Stock .....	91	8 7
„ Repayment of Income-Tax (3 years) .....	2	19 0	„ Balance at the Bankers', December 31st, 1904 .....	13	13 1
„ Cash received from Messrs. Flower & Flower, further on account of Legacy from the late Sir Joseph Prestwich .....	91	8 7			
	£115	1 8		£115	1 8

**'DANIEL-PIDGEON FUND.' TRUST-ACCOUNT.**

RECEIPTS.			PAYMENTS.		
	£	s. d.		£	s. d.
To Balance at the Bankers' at January 1st, 1904	14	11 8	By Award to Mr. L. Richardson	31	1 6
„ Dividends (less Income-Tax) on the Fund invested in £1019 1s. 2d. Bristol Corporation 3 per cent. Stock.	29	2 1	„ Balance at the Bankers', December 31st, 1904	15	18 5
„ Repayment of Income-Tax (2 years)	3	6 2			
	£46	19 11		£46	19 11

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

W. T. BLANFORD, *Treasurer.*  
January 20th, 1905.

H. BAUERMAN,  
HORACE W. MONCKTON, { *Auditors.*

*Statement of the Society's Property : December 31st, 1904.*

PROPERTY.	£	s.	d.
Due from Messrs. Longmans & Co., on account of Quarterly Journal, Vol. LX, etc. ....	70	10	9
Balance in the Bankers' hands, December 31st, 1904 : On Current Account .....	395	9	11
Balance in the Clerk's hands, December 31st, 1904 ....	13	17	8
Funded Property :—			
£2500 India 3 per cent. Stock .....	2623	6	0
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference-Stock ....	502	15	3
£2250 London & North-Western Railway 4 per cent. Preference-Stock .....	2898	10	6
£2800 London & South-Western Railway 4 per cent. Preference-Stock .....	3607	7	6
£2072 Midland Railway 2½ per cent. Perpetual Preference-Stock .....	1850	19	6
£267 6s. 7d. Natal 3 per cent. Stock .....	250	0	0
Arrears of Admission-Fees .....	94	10	0
Arrears of Annual Contributions .....	232	1	0

[N.B.—The above amount does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications.]

W. T. BLANFORD, *Treasurer*.

*January 20th, 1905.*

*Note.*—The investments in Stocks are valued at their cost-price.

Balance in favour of the Society .....	£	s.	d.
	12,539	8	1

£12,539 8 1



## AWARD OF THE WOLLASTON MEDAL.

In presenting the Wollaston Medal to Dr. J. J. HARRIS TEALL, F.R.S., the PRESIDENT addressed him as follows:—

Dr. TEALL,—

The Council have unanimously awarded to you the Wollaston Medal, in recognition of the value of your researches concerning the mineral structure of the Earth, and particularly of your contributions to the science of Petrology generally, and more especially to our knowledge of the structure and composition of the rocks of the British Islands.

With regard to the nature of those researches I need add nothing: the published work of a Wollaston Medallist is familiar to the students of our science in all parts of the world, and will remain in evidence to enable the geologists of the future to appreciate its value.

But, although this Medal has been awarded to you for your researches, not on account of these alone are we proud of you.

When presenting you to the degree of Doctor of Science *honoris causa* in the University of Dublin last year, the Public Orator referred to you as ‘a man as dear to all for the kindliness of his nature as he is admired by all for the profoundness of his learning.’ Thanks to this kindliness of nature, you have ever placed your great stores of knowledge at the disposal of other workers. How much work we thus owe to you will never be known, for in helping others you have ever acted on the principle of not letting your left hand know what your right hand doeth; but were it known, I can safely aver that it would be found to have promoted researches concerning the mineral structure of the Earth, to so great an extent as to render you doubly deserving of this Medal.

Each one of your predecessors, in the high post which you occupy as Director of the Geological Survey of the United Kingdom, has received the Wollaston Medal, and we welcome its award to you, who, like them, have done so much to foster the friendly feeling which exists, and will, I trust, ever exist, between the members of that Survey and other geologists.

That it falls to my lot to hand you this Medal is a source of keen pleasure to me. It is now more than a quarter of a century since we first met in our College; and since then I have indeed profited

greatly by your ever-ready help, and am pleased to take this opportunity of acknowledging it.

Dr. TEALL, in reply, said :—

Mr. PRESIDENT,—

To be enrolled on the list of recipients of the Wollaston Medal is, I need hardly say, an honour that I appreciate highly, and the pleasure that I feel is enhanced by the fact that my name will follow very closely upon that of Prof. Rosenbusch, to whom I, in common with all other petrographers, owe so much. I am vividly reminded to-day of a personal visit that Prof. Rosenbusch paid to me at Kew many years ago, of the kindly interest that he displayed in my early efforts in microscopic petrography, and of the encouragement that he gave me to pursue the study into which I had been initiated by my old friend and College-Tutor, Prof. Bonney. I feel especially indebted to these two former recipients of the Wollaston Medal, and I am glad of this opportunity of expressing my feelings towards them.

I thank the Council of the Geological Society for the very great honour that they have conferred upon me, and you, Sir, for the extremely kind words with which you have accompanied the Award.

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#### AWARD OF THE MURCHISON MEDAL.

The PRESIDENT then handed the Murchison Medal, awarded to Mr. EDWARD JOHN DUNN, of Melbourne (Victoria), to Prof. J. W. JUDD, C.B., F.R.S., for transmission to the recipient, and addressed him in the following words :—

Prof. JUDD,—

The Murchison Medal has been awarded to Mr. E. J. Dunn, in recognition of his valuable contributions to geological science by the preparation of his geological maps of South Africa, and his investigations concerning the occurrence of gold in Australia.

Mr. Dunn's career furnishes the world with an admirable proof, were such needed, of the value of the economic application of our science. Naturally attracted to the science, Mr. Dunn fitted himself for the pursuit of the special branch with which he has been

most closely connected, by study at the Royal School of Mines. Although his attention has been chiefly directed to gold-bearing rocks in Africa and Australia, he has not neglected branches of geology unconnected with economics, and has in particular contributed to our knowledge of Glacial deposits in different parts of the world. His labours in mapping portions of South Africa rendered him eminently qualified for the post to which he has now been called—the Directorship of the Geological Survey of Victoria.

Considering the great interest which the Founder of this Medal took in the geological conditions that have controlled the distribution of gold, the award of the Murchison Medal to Mr. Dunn seems peculiarly appropriate.

In conveying it to him, will you also wish him on our behalf a successful career in his new office, and remind him that the geologists of this island watch with interest and satisfaction the labours of their brethren in Greater Britain?

Prof. JUDD replied as follows :—

Mr. PRESIDENT,—

I regret that the period which has elapsed since the award of this Medal by the Council has not permitted of our receiving a reply to the announcement made to Mr. Dunn at Melbourne. I do not doubt, however, that, on his behalf, I may assure you of the sense which he entertains of the honour that has been conferred upon him by the award of the Murchison Medal. Thirty years have elapsed since Mr. Dunn made his first contributions to this Society, upon the then little-known geology of South Africa; and, during more than thirty years, he has laboured unweariedly in solving geological problems in our Colonies—first in South Africa, and afterwards in Australia. Besides the gratification given to the recipient himself, I feel assured that this Award—made by the Mother of geological societies to one so closely identified with the progress of our science in the Colonies—will be regarded by them as an act not less graceful than just. It will serve to convince those young and vigorous communities of our sympathy with, and interest in, their efforts to explore the geological features of the vast areas of the Earth's surface which constitute their heritage.

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## AWARD OF THE LYELL MEDAL.

In handing the Lyell Medal, awarded to Dr. HANS REUSCH, F.M.G.S., Director of the Geological Survey of Norway, to Sir ARCHIBALD GEIKIE, Sc.D., Sec.R.S., for transmission to the recipient, the PRESIDENT addressed him as follows:—

Sir ARCHIBALD GEIKIE,—

The Lyell Medal is awarded to Dr. Hans Reusch, as a mark of honorary distinction and as an expression on the part of the Council that he has deserved well of the science, particularly by his contributions to our knowledge of the Geology of Norway.

Born on that 'fragment of primeval Europe' extending through Scandinavia and Caledonia, which has been the training-ground of so many geologists of eminence, Dr. Reusch has zealously pursued the study of our science in his native land. Undeterred by the difficulties which beset the students of its rocks, and avoiding the pitfalls of hypothesis, he has garnered a store of information which is of very high value to the students of the crystalline schists. Nor has he confined his attention to these rocks, but has added to our knowledge of the Glacial phenomena of his country, and of recent years especially he has been attracted by the fascinating task of accounting for many of its surface-features.

The reception of the Medal by you, Sir, on Dr. Reusch's behalf but partially diminishes our regret at his absence this day. In conveying the Medal to him, will you at the same time convey the good wishes of the many workers in this country who are glad to number him among their friends?

Sir ARCHIBALD GEIKIE, in reply, said:—

Mr. PRESIDENT,—

It gives me great pleasure to be the medium of transmitting the Lyell Medal to my old friend, Dr. Hans Reusch. No one who is familiar with the progress of geology in Scandinavia during the last quarter of a century can have the least hesitation in cordially approving the action of the Council, in conferring this distinction upon him. He has thrown light on the oldest rocks of Norway and on the problems of metamorphism, and he has included the youngest geological phenomena within his ken. Having had the advantage of making traverses of his ground with him in the

north of Norway, I can bear witness to his keen powers of observation, and to the enthusiasm with which he employs them. We may hope that many years of active work are still in store for him, to the great advantage of our science. Dr. Reusch, in asking me to receive the Medal on his behalf, has enclosed a few words of acknowledgment, which I will now read:—

‘It is to me a great and unexpected pleasure to receive the Lyell Medal from the Council of a Society so celebrated throughout the scientific world.

‘It is the case with me, as with so many others, that the name of Lyell is allied with our earliest interest in the science dear to us all. I remember well, though I have not seen it for a good many years, the old copy of the first German translation of the ‘Principles,’ borrowed, when I was a boy, from the Museum in my native town of Bergen, and how I read in it with wonder of the evolution of the very earth that we are wandering upon.

‘In later years, during the “seventies,” when I was a student, the stout volumes of the “Quarterly Journal” in the University Library in Christiania were always of the greatest interest to me, as they appeared year by year; and it was a memorable day of joy to me when the news arrived, that I had myself the honour of being elected a Member of the Geological Society.

‘My work in the days left to me will be, I hope, in my native land of Norway. As your Society embraces the whole world in its survey of our science, it is my hope that such small sparks of truth as I may be able to add to what is known of the geology of Norway may be of some small interest to your Members. I return my heartiest thanks to the Council of the Geological Society for the great and undeserved honour which they have bestowed upon me.’

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#### AWARD OF THE BIGSBY MEDAL.

The PRESIDENT, in presenting the Bigsby Medal to Prof. JOHN WALTER GREGORY, D.Sc., F.R.S., addressed him in the following words:—

Prof. GREGORY,—

The Bigsby Medal is awarded to you, as an acknowledgment of your eminent services to Geology, the result of work carried on in many parts of the world.

The Founder of this Medal was himself a traveller. In the preface to his book ‘The Shoe & Canoe,’ he tells us that he spent six happy years wandering over the greater portion of the Canadas. He also did good service by his work in the study, as shown by his ‘Thesaurus Siluricus’ and ‘Thesaurus Devonico-Carboniferus.’ Could he extend his hand across the gulf, I feel that he would give a warm welcome to one who has earned this Award

by work in the study and the museum, and by explorations carried out in many lands, exposed at times to the scorching sun of Africa, at others to the icy blast of Arctic climes.

Worthy indeed are you to receive this Medal, which, in the terms of the Bequest, is to be awarded 'as an acknowledgment of eminent services in any department of Geology,' for we acknowledge your services in all departments of that science.

Prof. GREGORY replied as follows:—

Mr. PRESIDENT,—

It is impossible adequately to express my thanks to the Council for the honour of this Award, and to you, Sir, for the very kind words with which you have presented it. My only regret in connection with this Medal is that, owing to your many years of devoted service to the Society as its Secretary, your name does not appear on the roll of my predecessors.

The list of my contributions to geological literature includes a somewhat wide range of subjects, to which you have referred very kindly, although they may appear sadly disconnected. Of course, every geologist, who is not master of his own time, must devote most of his energies to work not of his own selecting. He must do what he should, and not what he would. I owe it to the sympathetic consideration with which the senior officials of the British Museum treat their assistants, that much of my work, when I was on its staff, had as close a bearing as it had, upon the problems in which I have been most deeply interested. My attention was first directed to geology, in order to understand the geography of the districts through which I rambled, and the, often, apparently-erratic course of the rivers. The bent that led me into geology, in order to understand local topography, subsequently roused my especial interest in the existing plan of the Earth. That interest has caused me to spend so much of my vacations collecting evidence in the 'back-blocks' of the Earth, that I have not yet had sufficient opportunity to work out the results. This Award will justify an attempt to secure more time for this work. One of the favourite proverbs of one of my old Zanzibar porters was 'whither good things go, thence good things should return.' The words of Bigsby's will show that this maxim inspired his bequest; and I am bound to make as good a return to our Science as I can for this valued Medal, and for the good wishes and cheering confidence which it betokens.

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## AWARD OF THE WOLLASTON DONATION-FUND.

In presenting the Balance of the Proceeds of the Wollaston Donation-Fund to Mr. HENRY HOWE ARNOLD-BEMROSE, M.A., the PRESIDENT addressed him as follows :—

Mr. ARNOLD-BEMROSE,—

The Council have awarded the Balance of the Proceeds of the Wollaston Donation-Fund to you, as an acknowledgment of the value of your investigations among the igneous and other rocks and the cave-deposits of Derbyshire.

In the intervals of a busy life you have done much to add to our knowledge of the geology of that county, and have also generously placed your services at the disposal of geologists visiting the district. We look forward with confidence to further work from your pen, and hope that you will receive this Award as an encouragement to you in carrying on your labours.

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## AWARD OF THE MURCHISON GEOLOGICAL FUND.

The PRESIDENT then presented the Balance of the Proceeds of the Murchison Geological Fund to Mr. HERBERT LISTER BOWMAN, M.A., addressing him in the following words :—

Mr. BOWMAN,—

There appeared at one time to be some danger that Mineralogy might be divorced from Geology. This Society has never ceased to recognize the relationship of the two sciences, and the Council acknowledge it on this occasion by awarding the Balance of the Proceeds of the Murchison Geological Fund to you, who are pursuing the study of the former science. The Council hope moreover that this Award may encourage you to prosecute further those researches in which you are already so far advanced,—researches in a science the study of which has received so great an impetus in your University by the labours of the distinguished occupant of the Waynflete Chair of Mineralogy.

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## AWARDS FROM THE LYELL GEOLOGICAL FUND.

The PRESIDENT then presented a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. EDWARD ALEXANDER NEWELL ARBER, M.A., addressing him as follows :—

Mr. ARBER,—

The Council have awarded a moiety of the Balance of the Proceeds of the Lyell Geological Fund to you, in recognition of your valuable contributions to our knowledge of Palæobotany.

In addition to the papers which you have contributed to this Society, I would specially refer to the paper on ‘The Fossil Flora of the Culm-Measures of North-West Devon,’ printed in the Philosophical Transactions of the Royal Society.

I hope that you will regard this Award as an encouragement to further work. Let me assure you of the pleasure which it gives me to hand it to a former pupil and present colleague.

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In presenting the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. WALCOT GIBSON, B.Sc., the PRESIDENT addressed him as follows :—

Mr. WALCOT GIBSON,—

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to you, as an acknowledgment of the valuable work done by you among the Carboniferous and other strata of the Midland Counties, as well as among the auriferous and associated rocks of South Africa, and as an encouragement to further research.

While pursuing your calling as a Geological Surveyor, you have been ever on the alert to utilize what has been written concerning the rocks which you mapped, and also to record your own observations, with results beneficial alike to the Survey and to the Science.

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## THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

JOHN EDWARD MARR, Sc.D., F.R.S.

In preparing notices of Fellows of the Society whom we have lost during the year, I have availed myself of the kind assistance of Dr. Bather, Prof. Bonney, Prof. Judd, Mr. Linsdall Richardson, Mr. Rudler, Dr. Teall, and Mr. H. B. Woodward.

FERDINAND ANDRÉ FOUQUÉ was born at Mortain (Manche) on June 21st, 1828. In 1849 he entered the École Normale, and, after completing his course of studies in that Institution, was appointed Keeper of the Scientific Collections, a post which he held from 1853 to 1858. His first piece of scientific work was done in 1853, in collaboration with Henri Ste. Claire Deville, and relates to the chemical composition of topaz; but it was not until the year 1861 that his attention was directed to those studies which have made him famous. In that year he accompanied Charles Ste. Claire Deville, as voluntary assistant, on a scientific expedition to Vesuvius, and thus commenced the long series of researches on volcanic action which terminated only with his life.

In 1869 he became attached to the Collège de France, and on two occasions (1873-74 and 1875-76) acted as deputy-professor, once for Élie de Beaumont, and once for his old master Charles Ste. Claire Deville. He succeeded to the professorship in 1877, and held the post up to the time of his death. He was elected a member of the Academy of Sciences on June 1st, 1881. He had been a Foreign Correspondent of our Society since 1885, when in 1889 he was transferred to the list of Foreign Members.

During a long and active career he took part in four scientific missions, organized by the Paris Academy of Sciences for the purpose of studying the phenomena of volcanoes and earthquakes. The eruptions of Etna in 1865, of Santorin in 1866, and of Terceira (Azores) in 1867 gave rise to three of these expeditions. The fourth was for the purpose of investigating the great Andalusian earthquake, which took place in 1885-86.

The scientific work of Fouqué relates almost exclusively to the phenomena which are connected either directly or indirectly with volcanic action. He carried out elaborate investigations into the chemical nature of the volatile products, the petrographical

characters of the igneous rocks, and the geological history of the volcanic regions which he visited. He was the first to introduce modern petrographical methods into France; and both by himself, as well as in collaboration with M. Michel Lévy, he improved and extended those methods. Moreover, it is to the joint work of those two investigators that we are indebted for the proof that many igneous rocks and minerals can be produced artificially by pure igneous fusion.

One of the most important investigations carried out by Prof Fouqué is that which relates to the volatile products associated with volcanic action. In these investigations he followed up the work of his old master, Charles Ste. Claire Deville, who had already pointed out that the dominant gases and vapours emitted from fumaroles vary with the distance from the volcanic vent and with the time which has elapsed since the period of maximum activity. Fouqué not only verified this law, but threw additional light on the subject. He showed that the variations observed are not due, as might be supposed, to the disappearance of certain gases and their replacement by others; but that the hottest fumaroles contain all the gases, and that the variations are caused by the progressive disappearance of those which are least volatile as the temperature falls. While carrying on these researches, which were often attended with personal danger, he demonstrated the existence of free hydrogen during the eruptions of Santorin, and thus proved that real flames not only may, but actually do, exist in association with certain types of volcanic activity; a fact which had often been denied.

In connection with his elaborate investigations into the petrographical characters of the lavas and other igneous rocks of Santorin, he devised two new methods for isolating the different mineralogical constituents, one depending on the use of the electromagnet and the other on that of hydrofluoric acid. Both these methods have proved to be of great general utility.

But Fouqué was not only an accomplished chemist, mineralogist, and petrographer. He was also a geologist. The mutual relations of the rocks in the field were carefully studied by him, and the events of which they are the records were placed in true chronological order. Thus, in his classic work '*Santorin & ses Éruptions*,' he shows that the earliest eruptions took place beneath the Upper Pliocene sea, that elevation followed, that subaërial activity resulted in the building-up of a central volcano, with

parasitic cones, on the site now occupied by the bay, that this volcano was clothed with vegetation, that its lower slopes were inhabited by a prehistoric race whose dwellings may now be seen beneath fragmental volcanic rocks, and that the present bay was formed by a grand paroxysmal eruption which destroyed the central cone.

In 1880, Fouqué was made a member of the Commission whose duty it is to prepare a detailed geological map of France, and, as his share of this important work, carried out during five consecutive years a survey of the Cantal.

In collaboration with M. Michel Lévy he brought out the well-known treatise on microscopical mineralogy, which has done so much to advance petrographical knowledge, and in which the mutual relations of the minerals of typical igneous rocks are shown in a series of coloured plates.

One of the most recent contributions to science by Prof. Fouqué is an elaborate treatise on the optical characters of felspars, in which a new diagnostic method is introduced, depending on the observation of the angles of extinction in sections perpendicular to the two bisectrices.

He held the professorship of Geology in the Collège de France for more than a quarter of a century, and throughout that long period never failed to interest his audiences in the results of the work on which he was engaged.

Although much of his work was done in the laboratory, he was an indefatigable field-geologist, and during his long sojourn in Auvergne gained the respect of the inhabitants by his simple mode of life and by the physical energy with which he carried out the arduous task of surveying the region. He was passionately devoted to science, and always ready to discuss the questions in which he was interested with fellow-workers of all nationalities, and to render them any assistance in his power.

He died suddenly, on the morning of March 7th, 1904.

[J. J. H. T.]

CHARLES EMERSON BEECHER, elected a Foreign Correspondent of this Society in 1899, died suddenly of heart-disease on February 14th, 1904, in his forty-eighth year. Beecher's high reputation as a palæontologist of Invertebrata depends neither on a multiplicity of papers, nor on numerous descriptions of new species. Trained in precise observation as assistant to James Hall, and combining an

acutely-philosophic mind with mechanical and artistic ability, he was well equipped for the task of applying to brachiopods, to trilobites, and to corals the principles of individual development and race-history enunciated in his own country by Cope and Hyatt. His classification of the Brachiopoda, based on these principles, is now generally accepted; while his later attempt to solve the still more difficult problem of Trilobite taxonomy and relationships has met with a cordial, if occasionally critical, welcome. His illuminating and suggestive papers on Palæozoic corals gave unfulfilled promise of yet another much-needed classification from his pen. The revision of Devonian Phyllocarida, presented by him to our Society in 1902, gathered up observations that he had accumulated since 1884, when the same fossils had formed the subject of his first independent publication. The patient enthusiasm, the lucid mind, and the dexterous hand, which enabled Beecher to leave such deep impressions on his chosen science, fitted him no less eminently for his combined profession of university-teacher and museum-curator. Of Yale's mourning and America's loss others have fully and fittingly spoken<sup>1</sup>; ours is the task of testifying to the admiration with which we here all regarded his active life, and the sorrow that fell on us in his sudden and too early death. [F. A. B.]

In Lieut.-General CHARLES ALEXANDER McMAHON, F.R.S., who died at his residence in Nevern Square, London, on February 21st of last year, our Society loses one who made himself a geologist among the mountain-defences of India and continued his studies after his return to England. A descendant of an old Irish family, and the son of Capt. Alexander McMahon, of the East India Company's service, he was born at Highgate on March 23rd, 1830, and obtained his first commission on February 4th, 1847, in the 39th Madras Native Infantry, where he served for eight years. After this he became a member of the Madras Staff Corps, and was transferred to the Punjab Commission. Here he did admirable work for thirty years as Commissioner and Judge. It was due to his nerve and promptness in action that, at the outbreak of the Indian Mutiny—in May 1857—just after he had taken charge of the Sialkot district, the revolted native troops were met and crushed by General Nicholson, then on the march to Delhi. His ability as a Judge was demonstrated by his decision in a complicated suit against

<sup>1</sup> For full references, see R. T. Jackson, in the 'American Naturalist' vol. xxxviii (1904) pp. 407-26.

the Indian Government, involving a sum amounting to above half a million sterling; for it was upheld on appeal by both the Superior Court in India and the Privy Council at home.

About the year 1871 McMahon, then Commissioner of Hissar, began to work at petrological questions, his first contribution, 'On the Blaine Group and the Central Gneiss in the Simla Himalayas,' appearing in the 'Records of the Geological Survey of India' in 1877. It was followed by 'Notes of a Tour between Spiti & Hangrang'; and subsequently, in 1879, while on furlough in England, then a Lieut.-Colonel, McMahon, with characteristic thoroughness, entered as a student at the Royal School of Mines, and attended the lectures by Judd, Huxley, and Warrington Smyth. The experience thus acquired was applied, on his return to India, to the thorough study of the crystalline rocks in the Himalayas; and he added no less than twenty-one papers to the two already published in the 'Survey Records.' About nine of these were petrographical—careful descriptions of rocks from various localities; but the remainder for the most part dealt with large petrological questions. He was working along the same lines, but quite independently, as a few, to whom at present he was hardly known, in England. In a paper on the Geology of Dalhousie, written about 1882, he states that he has arrived, from his own observations, at the conclusion that, as a rule, the extent of metamorphism affords an indication of the relative age of ancient rocks; and in a later paper, 'On the Microscopic Structure of some Dalhousie Rocks,' published in 1883, he proves the gneiss of that region to be a true eruptive rock, the structure of which is due to fluxional movements and pressure from adjacent rock-masses, at a time when the intrusive magma was still in a viscid or imperfectly-solidified condition. Thus he obtained for himself, while working as a pioneer in these great mountain-ranges, a firm hold on more than one important petrological principle.

After thirty-eight years' service he retired, but was promoted to Major-General in 1888 and Lieut.-General in 1892, and he settled down in London to work steadily at his favourite studies, publishing papers in the 'Mineralogical Magazine,' the 'Geological Magazine,' the Proceedings of the Geologists' Association, and the Quarterly Journal of the Geological Society. The more notable in the last were on the crystalline rocks of the Lizard district, where his Indian experience stood him in good stead, and on the phenomena associated with the Dartmoor granites; but he did not lose touch

with India, and co-operated with his son, Major A. H. McMahon, in a valuable account of the Geology of Gilgit, and after joining the Mineralogical Society in 1882 he contributed four papers to its Magazine. The first discusses the cause of a polysynthetic structure in some porphyritic quartz-crystals from India; the second describes the bowenite or pseudo-jade from Afghanistan, which he shows to be a true serpentine of somewhat unusual hardness, its probable origin being a rather exceptional peridotite; the third treats of the microchemical analysis of rock-making minerals, giving the results of his own experiences; and the fourth deals with the optical characters of the globules and spherulites of lithium-phosphate and some other salts.

He was a frequent attendant at scientific gatherings and an effective contributor to discussions, obtaining a reputation as a terse, clear speaker, who never rose unless he had something valuable to say. He became a Fellow of our Society in 1878, served more than once on our Council, being Vice-President in 1895-97, and received its Lyell Medal in 1899; he was President of the Geologists' Association in 1894-95 and of the Geological Section of the British Association at Belfast in 1902, and was elected a Fellow of the Royal Society in 1898.

Between two and three years ago his eyesight began to fail, so that he was obliged to resign, in June 1902, the Treasurership of the Mineralogical Society, to which he had been elected in the previous November; his general health then began to decline, and after several months' illness he died on February 21st, 1904. But, while the body was weak, the mind remained vigorous, for his last scientific writing, published in the 'Geological Magazine' for November 1903, shows all his wonted grasp of his subject and power of polished satire. One who has discussed with him, in the field and in the study, questions more or less controversial, may be allowed to add that as a worker none could be more thorough, cautious, and conscientious, while as a man he wore 'the white flower of a blameless life,' and combined unswerving rectitude of character with a remarkable gentleness of disposition. [T. G. B.]<sup>1</sup>

By the death of Sir CLEMENT LE NEVE FOSTER, Geological Science has lost one of the chief authorities on, and most able exponents of, its practical applications. The second son of Mr. Peter Le Neve

<sup>1</sup> This obituary has, in substance, also been published in the Mineralogical Magazine, vol. xiv (1904) pp. 56-57.

Foster, so long Secretary of the Society of Arts, our late Fellow was born in 1841, receiving his early education, firstly at a Collegiate School in Camberwell, and afterwards at a school in France. While still very young, he entered the Royal School of Mines, where he had a very distinguished career, carrying off the whole of the prizes and scholarships. After spending a year in the famous old Mining School of Freiberg in Saxony, and travelling in other parts of the Continent, he was offered in 1860 a post on the Geological Survey of England and Wales.

It was while engaged in the survey of the Wealden area that Le Neve Foster was able to make his most notable contribution to Geological Science. The peculiar and seemingly-anomalous system of drainage in the Wealden district had long attracted the attention of geologists. The rivers, instead of following what would seem to be the natural course from west to east into the North Sea, cut their way through narrow gorges in the North and South Downs, and flow into the Thames and the English Channel respectively. This phenomenon led Hopkins and others to suggest that the longitudinal fold of the Weald must have been accompanied by transverse fractures, along which the rivers had cut their courses. Murchison and Lyell, however, argued that the main portion of the denudation of the Wealden Anticline must have been due to marine action. Following the lead of Jukes in the famous memoir 'On the River-Valleys of the South of Ireland,' published in 1862 in the Journal of our Society, Le Neve Foster with his fellow-worker William Topley were able to show that the denudation of the Weald must have been effected by the existing rivers when flowing at higher levels than at present. In proof of this, they were able to describe in detail the terraces composed of fluvatile gravels, now seen at heights up to 500 feet above the present Medway Valley. These conclusions, published in 1862 in the well-known paper in our Journal, 'On the Superficial Deposits of the Valley of the Medway, with Remarks on the Denudation of the Weald,' established the reputation of Le Neve Foster and Topley as able observers and acute thinkers, and their results are now universally accepted.

In 1865 Clement Le Neve Foster left the Survey, and from that time forth his connection with geological research to a great extent ceased. Valuable papers, however, appeared from time to time from his pen, dealing with various mineral species and their detection by means of blowpipe-analysis, with the phenomena of

mineral-veins, and the characters of other ore-deposits. He became an Inspector of Mines in 1873, and in this position his great geological knowledge and wide experience led to his advice being constantly sought by the Government in connection with mining questions of especial difficulty. The long series of Annual Reports which he issued, as well as the contributions which he made to the second Royal Commission on Coal-Supply, bear witness to his untiring energy and to his extensive knowledge and his wide experience in all matters connected with the art of mining.

Not less important was his work as a teacher of the practical applications of our Science. First as Lecturer to the Mining School of Camborne from 1865 to 1868, and afterwards as successor to our former President, Sir Warington W. Smyth, as Professor in the Royal School of Mines from 1890 to the time of his death, he established a foremost place in connection with mining instruction in this country. Lucid as a lecturer, untiring as an author, beloved alike by his students and colleagues, Le Neve Foster lost his life as the result of his devotion to duty. While investigating the cause of a mining disaster in the Isle of Man in 1897, he was poisoned by carbonic-oxide gas, and, although his strong constitution enabled him partly to recover for a time, his heart had sustained such injury that he passed away somewhat suddenly on April 19th, 1904.

Sir Clement Le Neve Foster became a Fellow of this Society in 1863, and in 1892 was elected to the Fellowship of the Royal Society; he was a Bachelor of Arts of both the Paris and London Universities, and a Doctor of Science in the latter. In 1903 Le Neve Foster's great public services were recognized by his receiving the honour of knighthood. [J. W. J.]

FRANK RUTLEY, who had been a Fellow of this Society since 1870, was born at Dover, the son of a medical man, on May 14th, 1842. His scientific training was obtained chiefly at the Royal School of Mines, where he studied from 1862 to 1864. After holding for a brief period a commission in the Army, he joined the staff of the Geological Survey, and in 1867 he began field-work with Aveline and Clifton Ward in the Lake District. Here his attention was at first directed to the phenomena of glaciation, but he soon turned to the study of rocks—a subject which henceforth became the engrossing business of his life. Microscopic petrography, though initiated in this country, was rapidly developed in Germany; and Rutley's early education at a school in Bonn led him to follow



with avidity the new literature. Transferred from the field to the office, he became the petrographical authority on the Survey, examining and describing the rocks collected by his colleagues, and arranging the fine collection of rock-specimens in the Museum of Practical Geology. At a time when almost the only work on rocks available to the English student was Lawrence's translation of B. von Cotta's well-known treatise, Rutley felt that a text-book on Petrology was much needed, and he was consequently led to write for Longman's series of text-books his work entitled 'The Study of Rocks,' which was published in 1879. In later years he wrote two other works for students—one on 'Rock-forming Minerals' (1888) and the other on 'Granites & Greenstones' (1895).

To the Geological Survey, Rutley contributed a valuable memoir on 'The Felsitic Lavas of England & Wales' (1885), and another on 'The Volcano of Brent Tor' (1878). No fewer than twenty-six papers from his pen have been published in the Journal of this Society; and the complete list of his writings which appeared in the 'Geological Magazine' (July 1904, p. 334) is sufficient testimony to his scientific activity. In 1881 he received from the Council of this Society the balance of the proceeds of the Murchison Geological Fund. Mr. Rutley's papers were always illustrated by beautiful drawings, executed by himself and showing considerable artistic talent.

After fifteen years' service on the Geological Survey, Rutley was appointed Lecturer on Mineralogy, under Prof. Judd, at the Royal College of Science, South Kensington. In the lecture-room his fluency of speech, coupled with a charming modesty of manner, his manifest enthusiasm for his subject, and his remarkable skill at the blackboard, could hardly fail to render him a favourite with those who came under his influence as a teacher.

In 1898 Mr. Rutley was suddenly smitten by paralysis; but, on his partial recovery, he continued for some years to carry on his quiet microscopic work at home, and even contributed several papers to this Society. At length, however, further attacks compelled him to withdraw from all activity, and he remained for a long time a helpless invalid, yet retaining to the last his interest in the progress of his favourite science. The end came peacefully on the 16th of last May. [F. W. R.]

ROBERT FISHER TOMES, who died in July 1904, was elected a Fellow of the Geological Society in 1877. He was born at

Stratford-on-Avon in 1823, and remained there until 1879, when he removed to the house at South Littleton in which he died. Although he may have appeared to have lived a somewhat secluded life, it was nevertheless an extremely-active one. The administration of justice, educational matters, parish and county work, various branches of archæology, zoology, and geology, all received attention; whilst he was an excellent carver of old oak and an enthusiastic collector of old china—especially Worcester ware. For his researches in connection with the Cheiroptera he was elected a Corresponding Member of the Zoological Society of London, but in the same year directed his attention to fossil corals.

A considerable number of papers dealing with those organisms were contributed by Mr. Tomes to the Journal of this Society; and his name will be especially remembered in connection with the once vexed question as to the age of the Sutton Stone of Glamorganshire. He held that 'during the period of the deposition of the Rhætic Beds no such deposition took place at the locality in question [Bridgend]'; an opinion which he re-stated in 1877, and added, 'the Rhætic fauna of that period became in this manner mixed up with that of the true Lias which was subsequently deposited.' He held this opinion to the end, reiterating it in 1903, when describing in the Journal of this Society the Rhætic coral *Heterastræa rhætica* from the deposits of *contorta*-age at Deerhurst (Gloucestershire).

As his papers in this Journal and the 'Geological Magazine' testify, his knowledge of corals from the Mesozoic strata was considerable, and it is greatly to be regretted that he was not spared to communicate a paper which he was preparing on the revision of certain genera.

[L. R.]

ROBERT HARRIS VALPY, whose death took place on December 18th, 1904, was born on September 16th, 1819, and was consequently in his 86th year. He had been a Fellow of this Society since 1862, and although personally known to but few of our members, he had been an enthusiastic student of geology, and had made a special collection of fossils from the Devonian rocks of the neighbourhood of Ilfracombe. Robert Etheridge, in his classic paper 'On the Physical Structure of West Somerset & North Devon, & on the Palæontological Value of the Devonian Fossils,' published in our Journal in 1867, remarked (p. 605):

'No one has more carefully studied the Ilfracombe group of rocks than R. Valpy, Esq.; and to him am I indebted for considerable information

relative to fossil localities, permission to examine his rich Collection, and also his notes upon this part of the North Devon coast. He has himself catalogued and noted upwards of 50 species from the Ilfracombe group alone, a work of considerable time and labour.'

Again (p. 606), Etheridge stated that

'Mr Valpy has obtained in many places along the coast good evidence of the existence of fish through the remains of bones and coprolites, but no teeth or scales so as to enable us to determine their genera. None but a local observer can do justice to the difficult and obscure structure of this coast; and no one has worked it out so patiently as, or with more detail than, Mr. Valpy.'

Not a few men have similarly rendered service to science without any desire for recognition. Mr. Valpy was especially averse to publicity, and a little work which he wrote, entitled 'Notes on the Geology of Ilfracombe & the Neighbourhood,' was issued anonymously, 'by a Resident,' and in the fourth edition, 'by a late Resident.' It was published by Twiss & Sons, Ilfracombe, but undated. Mr. Valpy was educated at Harrow, and Balliol College, Oxford, and was the only son of Capt. Anthony B. Valpy, R.N., of Combe Lodge, Blagdon (Somerset). In 1849 he purchased the Enborne-Lodge estate near Newbury in Berkshire, and there he spent most of his time during the later years of his life. [H. B. W.]

By the death of WILLIAM FERGUSON, F.L.S., the Society loses a Fellow who had belonged to it for half a century, for he had been elected as long ago as 1854. He contributed to our Journal a paper on 'Chalk-Flints & Greensand found in Aberdeenshire' Quart. Journ. Geol. Soc. vol. xiii (1857) p. 88.

The Rev. HENRY BRASS, Vicar of St. Matthew's, Redhill, was a Fellow of our Society for nearly 50 years, having been elected in 1857. He took his degree at Cambridge in 1854, his name appearing in the Mathematical Tripos list and also in that of the Natural Sciences Tripos for the same year, with marks of distinction in Geology and Mineralogy. He was appointed Vicar of St. Matthew's in 1866. Though not a member of the Geologists' Association, he took a keen interest in the geology of the district around Reigate, and was always ready to let members of that Association know of new sections, and to give general assistance in connection with its excursions: for this he received the thanks of the Council at the Annual Meeting of the Association in 1895.

CHARLES RICKETTS, M.D., was born at Titchfield (Hants), in 1818.

but the greater part of his life was passed at Birkenhead, where he practised as a physician.

He was elected a Fellow of our Society in 1867, and contributed a paper on 'Some Erratics in the Boulder-Clay of Cheshire, etc., & the Conditions of Climate they denote' *Quart. Journ. Geol. Soc.* vol xli (1885) pp. 591-98. His principal contributions to our science are, however, contained in the 'Geological Magazine,' and in the Proceedings of the Liverpool Geological Society. He occupied the Presidential Chair of that Society in 1871-72, and at the time of his death was an Honorary Member.

Dr. Ricketts wrote papers on a great variety of subjects, including the Carboniferous strata and Glacial accumulations, but his best-known paper is that bearing on earth-movements, entitled 'On some Physical Changes in the Earth's Crust' (*Geol. Mag.* 1889, pp. 49, 115, & 165), where he refers to his geological models, copies of which are preserved in various museums.

A careful observer, an acute thinker, and a kindly companion, he was a typical example of the many busy professional men who are so often the leading spirits of local scientific societies.<sup>1</sup>

By the death of THOMAS WILLIAM SHORE at Balham, on January 15th of the present year, our science loses one who did much towards the encouragement of its study, and many of us mourn the loss of a valued friend.

Mr. Shore was for 23 years connected with the Hartley Institution (now Hartley University College) at Southampton, acting at various times as Secretary, Curator of the Museum, and Director. He also managed, and largely extended, the local Geological Museum.

In 1855 he founded the Hampshire Field-Club & Archæological Society, and was Honorary Secretary of that Society up to the time of his death. In 1896 he removed to London, and founded the Balham Antiquarian Society, of which he was the leading spirit. He also became Honorary Secretary of the London & Middlesex Archæological Society.

Though chiefly interested in Archæology, he did much for Geology. In 1882 he was Secretary of the Geological Section of the British Association at Southampton. He was a frequent attendant at the excursions of the Geologists' Association.

Most of his geological writings appeared in the Papers of the Hampshire Field-Club, including 'Ancient Hampshire Forests &

<sup>1</sup> Compiled chiefly from a notice by T. M. R., in *Geol. Mag.* 1904, p. 240.

the Geological Conditions of their Growth' (1888); 'The Clays of Hampshire & their Economic Uses' (1890); 'Springs & Streams of Hampshire' (1891), 'Hampshire Valleys & Waterways' (1895); 'The Physical Geology & Early Archæological Associations of the Neighbourhood of Cheriton' (1900); and a paper, written with Mr. Elwes, on 'The New Dock-Excavation at Southampton' (1889). He also wrote the geological article for the British Association Guide to Southampton and the neighbourhood (1882).

The Rev. HENRY PALIN GURNEY, M.A. (Cantab.), Hon.D.C.L. (Durham), was born in London in 1847, and educated at the City of London School and at Clare College, Cambridge; he took his degree in 1870, being 14th Wrangler, and obtaining a First Class in the Natural Sciences Tripos in company with J. Wale Hicks (afterwards Bishop of Bloemfontein) and Francis Darwin. He was elected to a Fellowship at Clare College, and, after a short period of parochial work, became a partner with the late Mr. Wren in the well-known 'coaching' establishment, through which so many candidates for examinations have passed. In 1894 he was appointed Principal of the Durham College of Science at Newcastle, where he also held the Professorship of Mathematics, and for some time the Lectureship in Mineralogy. He had previously acted as Deputy-Professor of Mineralogy at Cambridge, and on several occasions examined for the Natural Sciences Tripos.

He was elected a Fellow of this Society in 1877, but contributed no paper to our Journal, although he was the author of several books and memoirs, including a 'Manual of Crystallography.'

Principal Gurney's energy, ability, and courtesy caused him to be greatly esteemed at Newcastle as elsewhere, and, apart from the work connected with the College, he was an active member of many committees and other bodies engaged in affairs of divers kinds.

He died, as the result of an accident, on the mountains of Arolla, in August 1904.

FRANK McCLEAN, M.A. (Cantab.), Hon.LL.D. (Glasgow), F.R.S., F.R.A.S., M.Inst.C.E., was the son of J. R. McClean, F.R.S., the well-known engineer. Born in 1837, he was educated at Westminster School and at the Universities of Glasgow and Cambridge. His name appeared in the list of Wranglers in the Mathematical Tripos of 1859. He then adopted the profession of an engineer, and, being apprenticed to Sir John Hawkshaw, took part in the drainage of the Fenland. He afterwards became a partner in the

firm of Messrs. McClean & Stileman, and was engaged in important work in connection with docks and railways at Barrow-in-Furness and London. In 1870 he retired from business, and devoted himself to scientific work, connected especially with Spectroscopic Astronomy. In 1891 he received the Gold Medal of the Royal Astronomical Society. He had been elected a Fellow of our own Society in 1863.

In addition to his scientific work, Dr. McClean was engaged in many other studies. He has advanced his favourite science, not only by his researches, but also by his benefactions, including the foundation of the Isaac-Newton Studentships at Cambridge for the encouragement of study and research in Astronomy and Physical Optics. He died at Brussels in November 1904.

ISAAC ROBERTS, Hon.D.Sc. (Dublin), F.R.S., F.R.A.S., was born in Denbighshire in 1829, but spent the early years of his life in Liverpool. Engaged in business, he amassed a fortune sufficient to allow him to devote himself to scientific pursuits. At first he occupied himself with the study of Geology, and, among other papers, wrote one on the filtration of sea-water through the Triassic sandstones. He also conducted experiments on the movements of underground waters around Liverpool.

In 1890 he removed to Crowborough, where he died on July 17th, 1904. Though not losing his interest in Geology, he devoted his later years to the study of Astronomy, being especially interested in Stellar Photography, and he received the Gold Medal of the Royal Astronomical Society in 1895.

PERCIVAL FOWLER, M.Inst.C.E., was the son of the late Sir John Fowler. He was a well-known mining engineer, and at one time was engaged in the exploration of Dutch Guiana. He was elected a Fellow of this Society in 1882.

R. G. MACKLEY BROWNE, F.S.A., was an Officer of the Admiralty-Division of the Supreme Court of Judicature, and an authority on Admiralty practice. For twenty-one years he was Marshal of the Admiralty-Court, and wrote works on 'Admiralty-Procedure against Merchant Ships & Cargoes' and on 'The Statute-Laws of Merchant Shipping.' He was elected a Fellow of our Society in 1867. His interest in Geology is indicated by the fact that he read two papers before the Society. He died at Brighton in his 83rd year.

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As our Science advances, we become more and more dependent upon the followers of other sciences for fresh information with regard to the Earth's history. Anyone turning over the pages of the indexes of geological text-books, will be struck with the numerous references to the writings of astronomers, physicists, chemists, mineralogists, and biologists. At the same time something more than a superficial knowledge of one or more of the kindred sciences is necessary to the labourers in several branches of Geology. The successful palæontologist must needs be prepared by a careful training in botany or zoology, and the petrologist must know more than a little of chemistry and mineralogy.

It is not wonderful that, in these circumstances, there appears to be a feeling among some that Geology as a separate science will become extinct, and that in the future the really important contributions to the Earth's history will be made by students of other sciences.

There is, however, one part of our science which must ever remain the territory of the geologist, in which he will pursue his labours by those exclusively-geological methods which he has employed in the past. I refer, of course, to the arrangement of the events which, taken together, constitute earth-history, according to their proper sequence in time.

The general character of these methods is too well known to us to need comment here, but it may not be amiss to consider what progress has been made in this branch of Geology. I propose, therefore, to direct your attention to the Classification of the Sedimentary Rocks.

From the time of William Smith onwards, and mainly by the adoption of his principles, the classification of the strata has progressed towards perfection by the method of successive approximations, and progress has been in two directions—namely, the division of the strata of any one area in greater detail, and the correlation of the beds of different parts of the globe over ever-increasing areas: how far progress may be made in each of these directions is yet a moot point.

In considering our existing classification, let us at the outset imagine that sediment had begun to accumulate simultaneously over all parts of the globe, that the accumulation everywhere proceeded at uniform rates, and that the lithological characters of the sediments were always and everywhere identical. We should then be able to classify and correlate these sediments by actual

measurement; and further, if we knew the rate of accumulation, we should be in a position to discover the time taken for the formation of the whole mass. Our classification would be purely arbitrary. We might make a foot, or a yard, or 100 feet, our unit, and separate the whole mass of sediment into a number of divisions of equal value.

Actually, however, we find that the sediments of any particular period were not accumulated at the same rates in different areas, and also that the sediments of different parts of the geological column in one area are dissimilar, and that those of the corresponding parts of the column in two areas may also be dissimilar. If, then, we could obtain a mass of sediments constituting a geological column in any area by sinking a gigantic bore to the bottom of the column, and we were to lay that column flat, we should be able to study the variation in the sediments of the column as regards lithological characters and organic contents, reading them off, say, from left to right. Such a column would bear some resemblance to the meteorograms, or tracings of the meteorological instruments, which are obtained in order to detect the weather-changes in a place from time to time; and we may find it useful to institute a further comparison between these meteorograms and the records of the geological columns of various parts of the world. The latter, for the sake of simplicity, I propose to speak of in this address as *geograms*.<sup>1</sup>

In a meteorogram we may have barograms, or lines representing barometric oscillations; thermograms showing changes of temperature; anemograms recording variations in the direction and velocity of the wind; and lines recording the amount of rainfall. Some of these are curved or zigzag, others broken lines.

In the case of a geogram formed of a narrow column, most of the lines, whether separating strata of different lithological characters or those containing different assemblages of organisms, will be practically parallel; but if the geogram be wide, representing, say, 500 miles of the sedimentary column, the lines, like those of the meteorogram, will be in some cases broken, in others zigzag.

The two principal types of lines of a geogram will be those

<sup>1</sup> I here use this term, which is (in many respects) strictly comparable to that of meteorogram, in place of the expression 'geological column,' for the latter unconsciously leads one to imagine a thickness of sediment of small diameter. A geogram may be of any width up to that of the circumference of the earth. The term is, however, merely used for purposes of comparison: I do not advocate its adoption.



representing change of lithological character, and those which mark change in the assemblages of organisms. Each type may be marked by broken or by zigzag lines. A particular kind of sediment may accumulate locally, while adjoining tracts are not receiving sediment; or an organism, or group of organisms, may spread out from a place for a short distance around the point of origin. These would give rise to discontinuous lines in the geogram. Again, owing to changes in the position of the sea-coast, the strip of coastal sediment may shift. If, for instance, a coast facing a sea to the west of it is undergoing submergence, the coastal sediments will be deposited more and more to the east, as the land sinks, and, when submergence is replaced by emergence, these sediments will be deposited more and more to the west, reposing on a wedge of deeper-water sediments, which were formed when the coast lay more to the eastward. In this way a V-shaped deposit of coastal sediments will be accumulated, with the apex of the V pointing eastward. A series of such oscillations will give rise to a series of V's, forming a zigzag line with the apices pointing alternately eastward and westward. The same thing will, of course, occur with the various deeper-water sediments.

Similarly, migration of organisms may cause a dominant organism, or group of organisms, to be distributed throughout the strata in zigzag lines. These lines may sometimes coincide, in whole or in part, with those marked by variation in the lithological characters of the strata, or may run independently of the latter.

But the lines of a wide geogram, unlike those of a meteorogram, will be blurred. The sediments will pass one into the other laterally as well as vertically, and the assemblages of organisms will not change suddenly as a whole, but more or less gradually.

The planes of bedding will also appear irregular in a wide geogram. Two planes, when traced laterally, will often come together, and a plane which is well-marked in one place may completely disappear elsewhere.

Accordingly, though any lines which we observe will probably appear parallel in a narrow geogram, they will vary in an irregular manner in one of considerable width. Now, in the meteorogram we have another set of lines. Vertical divisions are drawn through the meteorogram to mark days, and minor ones to mark hours. These are absent in the geogram, and it is the task of the stratigraphical geologist to attempt, as far as possible, to draw lines separating one synchronous strip of strata from another. The

meteorologist has his chronometer with which to separate one set of synchronous events from the next; the geologist can only attempt to draw chronometric lines by careful study of the tracings of the geogram. I mention this obvious fact, because it appears to me that, notwithstanding its obviousness, there is a tendency to compare the lines of the tracings with the chronometric lines.

If the meteorologist had no chronometer, but merely a set of continuous records traced on paper which had moved at uniform speed, he would be able, in dealing with some of the records, to construct a time-scale by observation of the tracings themselves. Merely-local changes in the direction of the wind or in the amount of rainfall would throw little light on this subject, but he would soon find that there were diurnal and annual variations in the changes of air-pressure and of temperature, and by means of the latter especially he would be able to divide the strips recording the traces into lengths corresponding with day and night, and with summer and winter. Even if the paper on which the tracings had been recorded had not moved at uniform speed, this could be done, although, in this case, the length of the paper containing the records of one day would differ from that of the paper containing those of another.

The more widespread the meteorological changes thus recorded, the more useful would they be found for establishing a time-scale, those of the greatest utility being due to extra-terrestrial, and not merely to geographical, causes.

By means of these widespread meteorological changes we could, if we had a series of meteorograms from various parts of the world, beginning simultaneously at each part, construct a time-scale which would enable us to correlate as regards date, minor changes which had occurred in widely-distant regions. But, apart from these, correlation of events could also be made in the case of less widely-distant regions, by using records of less widespread, though not purely-local character. Similar records in some cases would not be due to events happening quite simultaneously in two tracts, as, for instance, in the case of an advancing storm-area; these, however, would not seriously confuse the skilled meteorologist.

Now, this is very much the state of affairs as affecting the geologist, when concerned with the study of geograms. Having no chronometer, he must use the tracings on the geogram to establish his time-scale. The records of the geograms are not made at a uniform rate, and one of the tasks which confronts him is the endeavour to discover any periodicity of occurrence of certain events

which may be ultimately utilized for the purpose of constructing a time-scale, such as will not only enable him to detect events which happened synchronously in different parts of the world, but also will give him a clue to the actual lengths of the intervals of time indicated by various lengths of the geograms.

The principal variations in the records of these geograms are due to alternate formation and cessation of deposit; to differences in character of the deposits, owing to various local conditions; to accumulation of contemporaneous volcanic materials; to variations in the nature of the earth-movements; to changes in the nature of the included organisms; and, lastly, to climatic changes. Some of these are, of course, to some extent dependent upon the others, but it will be convenient to deal with them separately.

We may proceed to consider the significance of these records, as bearing upon the classification of the sedimentary rocks.

### (1) Alternate Formation and Cessation of Deposit.

Apart from the frequent existence of a plane of stratification between dissimilar deposits, to which further reference will be made, we frequently find two similar masses of deposit separated by a plane of stratification marking a want of coherence between the materials of the two masses. Such a plane of stratification is generally recognized as denoting a period of cessation of deposit; and it is equally recognized that such cessation may be due to various causes, such as shifting currents, alteration of the position of main discharge of a river, or establishment of a river's base-line of erosion, which may stop the supply of mechanical sediment in any area.

In the case of organic deposits, important bedding-planes indicate the temporary disappearance of the rock-forming organisms from the area; and although this temporary disappearance may again be brought about in many ways, climatic change is eminently qualified to cause cessation from the deposit of organically-formed beds to occur and recur with some approach to regularity. This was long ago recognized by James Croll, who suggested the formation of important bedding-planes in some limestones owing to climatic changes. He remarks<sup>1</sup> :—

‘In Derbyshire and in the South of Ireland and some other places, the limestone is found in one mass of several hundred feet in thickness without any beds of sandstone or shale, but then it is nowhere found in one continuous

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<sup>1</sup> ‘Climate & Time’ 1st ed. (1875) p. 434.

mass from top to bottom without any lines of division. These breaks or divisions may as distinctly mark a cold period as though they had been occupied by beds of sandstone. The marine creatures ceased to exist, and when the rough surface left by their remains became smoothed down by the action of the waves into a flat plain, another bed would begin to form upon this floor so soon as life again appeared.'

We need not necessarily assume with Croll that the beds of limestone represent warm interglacial periods, and the planes of division cold periods of glaciation, for change of climate, apart from glaciation, might be sufficient to cause the temporary disappearance of the rock-builders. I shall presently recur to this question of climatic change; I have mentioned it here, because it appears to me to be worth while to make a series of observations of widespread masses of pure limestone, with the object of noting the vertical distances which separate a series of dominant bedding-planes in such masses of pure limestone, like those to which Croll refers, and also the horizontal distances to which these dominant planes can be traced. Comparative regularity in the thicknesses of successive strata which can be traced far laterally, implies the comparatively-regular occurrence of the cause. It is these regularly-recurrent events which, if they happened, we should wish to detect.

## (2) Differences in the Characters of Successive Deposits.

We noted that the lines of the geograms would be blurred, owing to vertical and lateral passage from one kind of sediment into another. A sandstone, for instance, will not necessarily be markedly separated from a shale, but may gradually pass into it (either vertically or laterally) by the mixing of argillaceous with the arenaceous material in ever-increasing proportion.

But, in addition to this, there is another reason why the lines of the geograms should be less defined than those of a meteorogram. The lithological characters of a group of sediments are the product of many factors; and the conditions which produce similarities of one kind in these sediments may have a lateral distribution different from those which cause similarities of another kind, and the two sets of conditions may also change in any area at different times. Thus, a sandstone may be accumulating in one area, while a mud is being deposited in an adjoining tract. A supply of mica may be carried into these two tracts simultaneously, giving rise to a micaceous sand in the one, and to a micaceous mud in the other. The supply of mica might conceivably be cut off, though the materials which

were laid down as sand in one tract and mud in the other were still supplied: in that case, the micaceous sand would be overlain by one not containing mica, and the same would occur with the mud. In the case used for purposes of illustration, the presence of mica would be of use as a means of correlation, while the bulk of the material composing the rocks would not, for sand was being formed in one place while mud was being formed in another.

The above imaginary case is used to emphasize the importance of taking into account all the lithological characters of rocks, and not merely those which appear to be dominant, when studying strata with a view of classifying them. We are so accustomed to consider the calcareous, argillaceous, or arenaceous characters of sediments as of primary importance, that we are apt to overlook the significance of other characters, which, in some cases at any rate, may actually be of greater import than the composition of the rock. To illustrate this, we may take note of a few cases.

The British Jurassic rocks above the Lias contain limestones of very different characters, but in these the frequency of oolitic structure is so great as to have justified the use of the term 'Oolites' for them, although this structure is of course not always present, and is also frequent in British limestones of other date. Still, the common occurrence of oolite in rocks of Jurassic age over a wide region, indicates that some physical conditions were sufficiently prominent in those times to give rise to the structure over our area in an exceptional degree.

The Devonian rocks of North-Western and Central Europe contain an abundance of calcareous deposit. In these tracts, white crystalline limestones are particularly abundant in the beds of Middle Devonian age and of the earlier Upper Devonian age; while, in the later Upper Devonian rocks, nodular earthy limestones of a prevalent grey colour are especially frequent.

A very interesting case is presented by certain muddy deposits of the Silurian Era. In Bohemia, the beds *E 1* of Barrande contain faunas of Llandovery, Tarannon, Wenlock, and Lower-Ludlow ages. The strata of the three first-mentioned periods are, as a whole, remarkably similar in lithological characters, though containing different faunas; whereas, in Britain, the graptolite-bearing rocks of these ages differ one from the other more markedly. But in Bohemia, as in Britain, Scandinavia, and France, the shales which contain the Wenlock fauna are marked by the frequent occurrence of large elliptical concretions, often having *Orthocerata* or clusters

of graptolites as nuclei. These nodules are probably not absent from the other deposits mentioned, but in any case are much rarer therein. In Wenlock times, then, some physical conditions existed which caused the accumulation of strata of a type adapted to the formation of elliptical concretions within them.

We have no indication as to the nature of these conditions; the point of importance to us is that, owing to some cause or causes, a comparatively-inconspicuous character of certain rocks is found, as the result of observation, to be of greater value as a time-index than other characters which are more obvious.

It is only by observation that the relative values of different lithological characters can be gauged, and accordingly very detailed observations of these characters are important. Apart from the composition of the rocks, information of use for classificatory purposes may sometimes be obtained by noting such features as the closeness of the lamination of muds, the nature of the minor jointing of the beds, and the mode of preservation of the included organisms. For instance, the muddy rocks of many parts of England and Wales are often found to be more finely laminated among the Silurian rocks than among those of Ordovician age; the peculiar nature of the jointing of the Menevian rocks of Wales distinguishes them from argillaceous rocks of *Lingula*-Flag age, which are otherwise somewhat similar; and, in the Cambridge district, the preservation of the ammonites of the Ampthill Clay in phosphate enables us to distinguish that formation from the Oxford Clay of the same region, where the ammonites are preserved in pyrites.

The more detailed study of the petrography of the sediments, which is now being pursued after a period of comparative neglect, may throw unexpected light on the value of lithological characters for purposes of time-classification.

### (3) Accumulation of Contemporaneous Volcanic Materials.

The occurrence of the products of contemporaneous volcanic action is, of course, useful locally in determining the age of strata, although, owing to the frequent shifting of vents, it is dangerous to use this evidence over very wide areas. For instance, in many parts of the British Isles, the existence of much contemporaneous volcanic material in Ordovician times, and its absence from the Silurian strata, furnishes a ready means of distinction; but the presence of Silurian volcanic rocks in the Tortworth area

and in the South-West of Ireland, shows the strictly-local value of the test in the case of these Lower Palæozoic rocks.

I have elsewhere commented upon the comparative absence of volcanic rocks from the sediments of Jurassic and Cretaceous ages, which is in so marked a contrast with their abundance in Palæozoic and Tertiary times, suggesting a period of comparative quiescence from volcanic activity in the later Mesozoic Era. How far this apparent absence is due to our want of knowledge, remains to be seen; but, considering the extensive development of known Jurassic and Cretaceous rocks over so many different parts of the world, I cannot help thinking that the rarity of observed cases of volcanic ejectamenta among these rocks indicates a period of lull.

#### (4) Variation in the Nature of the Earth-Movements.

It is unnecessary to comment upon the influence of earth-movement in affecting the lithological characters of the sediments. The alternation of movements of a positive and negative character has been utilized as assisting in the classification of sedimentary rocks, but the applicability of this to areas of wide extent is a matter upon which some difference of opinion still exists. A study of the strata over those parts of the world which have been investigated in fullest detail, vaguely suggests the predominance of positive movements over very wide areas at the end of pre-Cambrian times, and later during the Devonian, Permo-Triassic, and Miocene Periods, and of negative movements in the intervals between these periods. But it is doubtful how far this suggestion is due to our imperfect knowledge. The influence of the Scandinavian movements over regions where geology has been most assiduously studied may, for instance, give us an exaggerated notion of the importance of positive movements in Devonian times; and even in Europe we find, in passing southward, a continuous development of marine sediments connecting those of Silurian with those of Carboniferous times. These may have been laid down in an ocean extending far to the south, for when we next meet with deposits of Devonian age, namely in South Africa, they are of marine origin.

At one time, the existence of physical breaks in the succession of the strata, owing to the occurrence of positive movements, was very largely utilized for classificatory purposes, many of the major divisions or systems of the sedimentary rocks having been defined owing to the existence of unconformities separating the rocks of

one system from those of another. Subsequent researches showed, however, not only that many of these physical breaks were of limited horizontal extent, but also that other important physical breaks, which had escaped detection, existed in the hearts of many of the systems as originally defined. We know, for instance, that important unconformities occur in our own country in the Ordovician, Carboniferous, and Cretaceous rocks; and, as our classification has undergone gradual modifications in the light of more extended knowledge, the importance attached to these physical breaks for classificatory purposes has steadily diminished, although their local value is, of course, still recognized.

As the result of earth-movements, cleavage and other metamorphic effects are sometimes available to assist us in separating the rocks into groups, yet these effects have on the whole but a local distribution, and mere allusion to them will accordingly suffice.

#### (5) Changes in the Nature of the Organisms included in the Strata.

With the advance of our knowledge of the strata and their contents, the importance of fossils has become more and more generally recognized; but, even now, geologists appear to be impressed with their value in different degrees. The writings of eminent men of science who had not received a definite geological training have, at any rate until quite recently, been quoted to show the danger of correlation of the strata of different areas by means of their included fossils, and much has been made of apparent anomalies of distribution, notwithstanding that most of these apparently-anomalous cases have already been proved to have been founded on stratigraphical or palæontological errors. I have elsewhere touched upon this question, but in any discussion concerning the principles of chronological classification of the sediments it is necessary to pay particular attention to the assistance which fossils furnish to those who are engaged in the classification.

The tracings of the fossils on the geograms are, like those made by lithological variations, of a blurred character, for more than one reason.

In the first place, there are errors of identification, and, apart from this, difference of opinion among geologists as to which characters are of specific value, and accordingly the vertical ranges



of many forms are still undetermined. This will, of course, become a less serious matter as our knowledge progresses.

Another difficulty is due to discontinuous vertical distribution of various organisms in many areas, causing certain organisms to recur after their disappearance from an area for some time. Such recurrences may take place after longer or shorter intervals of time. Remarkable examples of recurrence after long periods are furnished by the trilobite *Æglina rediviva*, which is found in the beds  $D_1$ ,  $D_3$ , and  $D_5$  of Bohemia, but not in  $D_2$  and  $D_4$ , as was long ago pointed out by Barrande; by the Olenids, which, abounding in rocks of *Lingula*-Flag age, are rarer in those of Tremadoc age, and, after apparent absence in Arenig and Llandeilo rocks, appear in some force in Caradoc times in the forms of the genera *Cyphoniscus* and *Triarthrus*; and by yet another trilobite, *Ampyx*, which, essentially an Ordovician form, is known in the Llandovery rocks of Scandinavia and Britain and in the Ludlow rocks of Britain and Bohemia, but has not yet been found in strata of Wenlock age. These forms must, of course, have existed somewhere during the periods when the rocks were deposited in which the fossils have not been found, and will no doubt be eventually discovered. These recurrences after long periods of apparent absence would be difficulties in the way of the correlation of strata by their organic contents, if they occurred with frequency; but they are by no means common, and usually exist in the case of a small percentage only of the total forms of the fauna.

Recurrence on a minor scale is quite common, as we might naturally expect, and even when the remains of an organism are distributed throughout a certain thickness of strata, they are apt to occur in exceptional abundance at some horizons, and to be sparsely distributed at others. Reference is made to this point, in order to show the importance of obtaining suites of fossils from all parts of a mass of sediment so as to become properly acquainted with the characters of its fauna. The absence of a fossil from beds in which it might be expected to occur is often asserted after insufficient observation, the particular belt of rock in which the remains of that fossil are preserved not having been carefully examined.

Again, the blurring of the tracings made by organisms is due to the changes in faunas not having taken place suddenly, but by extinction of one form at one time and of another later, and similarly with their incoming. Owing to this, we cannot define a

plane over a wide area separating fauna from fauna, any more than we can define such a plane separating beds of one lithological type from those of another over wide tracts of country.

A short space may be occupied with some remarks upon the separation of fossils into species. In the case of organisms of which the hard parts only are preserved, it is difficult to distinguish between species and varieties. For purposes of classification of the sediments, however, it is immaterial whether a particular assemblage of individuals can or cannot be referred to as a species, so long as these individuals present certain characters in common whereby they can be identified, and also distinguished from allied forms. Even if the assemblage constitutes only a variety from another assemblage, so long as it is found in beds of different age from those which contain that other assemblage, it is useful for classifying the beds. Whether these varietal assemblages coexisted with the allied forms, or lived subsequently to them, is a matter for determination by observation.

The study of mutations has already been carried on to some extent, but much more work remains to be done in this direction.

The mention of mutations reminds me that there has been some misconception concerning the use of the terms mutation and circulus. As it is most desirable to have a clear conception as to the proper signification of these terms, I have applied to Dr. F. A. Bather, who has kindly supplied me with definitions of the terms and a discussion thereon. I offer my sincere thanks to him for these notes, which provide geologists with a clear statement of the precise meaning of the terms, drawn up by a recognized authority. Dr. Bather writes:—

‘The term mutation was introduced by W. Waagen in 1869, on p. 186 of his work “Die Formenreihe des *Ammonites subradiatus*, &c.” (Geogn.-palæont. Beiträge ii, Heft 2, b), for the express purpose of distinguishing variations in time, to which alone this term is applied, from contemporaneous variations in space, for which the term variety was and is in universal use. Both are considered as modifications of a single specific form which, together with all its varieties and mutations, is termed a collective species (Collectivart). The time-series alone, that is to say, the original or root-form with its successive mutations, constitutes the Formenreihe, a term subsequently translated by Waagen himself as developmental series (Palæont. Indica, Jurassic Fauna of Cutch, Cephalopoda, pt. 4, p. 238, 1875). It was the opinion of Waagen that varieties were very variable and of little systematic value, whereas mutations were, even in trivial characters, exceedingly constant, and formed definite steps in evolution. Each mutation therefore might legiti-

mately be given a binominal designation on the Linnæan plan; but, to mark the fact that it was a mutation, this was connected by the symbol  $\sqrt{\text{---}}$  with the name of the species from which it was believed to be descended. Thus the name of a descendant of *Ammonites subradiatus* might be written either as *Ammonites subcostarius*, Opp. ( $\sqrt{\text{---}}$  *subradiatus*, Sow.) or *Ammonites subcostarius*, Opp.  $\sqrt{\text{---}}$  *subradiatus*, Sow. In every case the name of the oldest-known form in the developmental series was to be taken as the radicle, although with the progress of knowledge this might involve a change in the complete designation of any one mutation.

‘From Waagen’s statement as to the constancy of mutations, it might be inferred that he believed them to represent discontinuous variations or saltations. This, however, is nowhere definitely expressed by him, and, since he favoured the view that they resulted from some law of development innate in the organism (1869, p. 239, & 1875, p. 243), it might equally well be supposed that he regarded them as stages of a progressive, continuous growth, appearing to us as separate steps only because of gaps in our knowledge. To-day the historian of *Ammonites* will probably maintain the latter view, and in this he will be supported by many students of other fossil organisms, even of *Vertebrata* (see, for instance, Prof. H. F. Osborn, in “The Present Problems of Palæontology” *Pop. Sci. Monthly*, Jan. 1905, on p. 230). The question is one of fact, and the term *mutation* should be maintained, quite apart from the answer that may ultimately be agreed upon. Therefore, palæontologists should protest against any attempt to restrict the term to professedly-discontinuous variations, especially as these are already provided with the excellent term *saltation*. This, unfortunately, is the attempt that has been made by Prof. Hugo De Vries, in his book “*Die Mutationstheorie*” (Leipzig, 1901: see especially pp. 46-51), a work of such importance and renown that the protest against this particular mutation of terminology must needs be a strong one.

‘A mutation, in the palæontological and original sense, may be defined as a contemporaneous assemblage of individuals united by specific identity of structure *inter se*, and by common descent from a known pre-existing species, from which they differ in some minute but constant character or characters. Such mutations are successive steps of a genetic series, and each may be considered as of specific rank and may have its own contemporaneous varieties.

‘The term *circulus*, as Prof. J. F. Blake has kindly pointed out to me, was used by C. G. Ehrenberg, in “*Symbolæ Physicæ: Animalia Evertebrata, Series Prima*” 1831, to denote a classificatory division less than a Class and greater than an Order. Thus the *Anthozoa* and *Bryozoa* each constitute a *circulus* of the Class *Phytozoa*.

‘In 1896 the term was employed by Prof. J. W. Gregory, in the British-Museum Catalogue of Jurassic *Bryozoa*, to denote “certain convenient groups [of species], which are not altogether artificial, but which are not genera in the sense in which that term can be used among *Echinoidea* and *Mammals*.” Study of the whole chapter shows that the term combined two conceptions, and this has led to a misunderstanding of it in certain quarters. “The essential idea,” writes Prof. Gregory (*in litt.*, Nov. 18th, 1904), “was that the members of such a *circulus* were not homogenetic, but a casual assemblage of individuals derived

from different groups of individuals." To the exposition of this idea, as applied to Bryozoa, eight pages were devoted in the Catalogue. But, in order to justify the adoption of the word *circulus*, the paragraph introducing it laid stress on the subsidiary idea of indefiniteness (p. 22): "A *circulus* was one of the small groups of individuals who clustered round speakers in the Roman forum. Most of the individuals in the forum were definitely attached to a particular group; the groups were less crowded around their margins, and between them people were irregularly scattered and crossed from *circulus* to *circulus*. They thus prevented any rigid division of the crowd into definite groups." It is clear, however, from Prof. Gregory's own words, that the application of the term *circulus* to a group of individuals, whether of supposed generic or specific rank, implies not merely that the group has uncertain limits but that it is polyphyletic.

'A *circulus*, in short, is an ill-defined assemblage of approximately-isochronous homœomorphs, which it is either inconvenient or impossible to distribute among well-defined homogenetic genera or species.'

That different organisms are of very different values for purposes of classifying the sediments is well known, and the reasons for the differences of value are in some cases known, in others obscure.

Those organisms with a long range in time are, of course, mainly valuable for defining considerable thicknesses of strata; while those which had a shorter range may be utilized for separating the smaller divisions. We cannot always infer, however, which organisms will be found to possess a long and which a short range, for in the case of some groups certain genera have a very long range, and others that are closely allied have a brief one: compare, for example, the two brachiopods *Discina* and *Trematis*.

Of shallow-water forms, those which belong to the benthos are particularly suitable for determining the facies of the containing deposits. This is especially true of the organisms appertaining to the sessile benthos, and in a less degree to those of the vagrant benthos, for the benthic organisms existing in tracts where the physical conditions—such as temperature, amount of light, and characters of the sediments of the sea-floor—vary rapidly, are limited as to their horizontal range by the distribution of those conditions which determine their station. As these conditions often change in any area with considerable frequency, the organisms are of course locally useful for chronological division of strata, but, owing to the usually-restricted horizontal range of the forms, they are of little value for correlating strata over wide areas.<sup>1</sup>

<sup>1</sup> For information concerning the uses of the planktonic, nektonic, and benthic organisms of past times to the geologist, see J. Walther, 'Ueber die Lebensweise fossiler Meeresthiere' Zeitschr. Deutsch. Geol. Gesellsch. vol. xlix (1897) p. 209.

As the physical conditions of the deeper parts of the ocean are more uniform over wide areas than those of the shallows, the deep-water benthic forms are more valuable for purposes of correlation of remote sediments; and this is, of course, especially true of the forms belonging to the vagrant benthos.

But it is to the members of the nekton and the plankton (including in the latter the mero-plankton and the pseudo-plankton) that we turn with the greatest confidence as being likely to furnish us with the means of correlating strata over wide areas. These easily-distributed organisms may have spread over wide tracts of ocean soon after they came into existence, and if their period of endurance be long as compared with the time taken for spreading from their centres of origin, they will give most important information for purposes of correlation. As their remains may be embedded in the sediments of the shallows and the depths alike, they are also useful for comparing the beds of shallow-water with those of deep-water origin; whereas the benthic forms of these deposits will probably differ. To take an example, we may allude to the graptolites, which, according to Prof. Lapworth, constituted members of the pseudo-plankton of Lower Palæozoic times. The faunas of the normal graptolitic type of sediment often consist almost entirely of graptolites; while the deposits of the shallows of the same ages usually yield a variety of organisms belonging to many different zoological groups. Here and there, however, we come across a few graptolites associated with the other fossils, which enable us to correlate the shallow-water deposits with those of the normal graptolitic type, as has been done so successfully by Prof. Lapworth himself in the case of the richly-graptolitic deposits of the Moffat district and the contemporaneous shallow-water sediments of the Girvan area.

In future work on the faunas of the sediments, the effects of homœomorphy must be regarded more carefully than has been done in the past. Cases of contemporaneous homœomorphy, such as appear frequently to occur among the graptolites, do not vitiate the conclusions of the stratigrapher; but, when homœomorphy occurs in the case of organisms which lived at different times, it may lead the student to arrive at wrong conclusions. For instance, the graptolites of the genus *Azygograptus* might at one time have been mistaken for forms of *Monograptus*; indeed, before the significance of the position of the sicula was appreciated, the diagnosis of the genus *Monograptus* was so drawn up that forms of *Azygograptus* would have been referable to that genus. The apparent similarity in

outward form of these genera is not due, however, to a very close genetic relationship; and whereas *Azygograptus* is characteristic of early Ordovician strata, *Monograptus* is confined to those of Silurian age. Similar cases of non-contemporaneous homœomorphic forms have been noted among the ammonites and the brachiopods, and will probably be detected in the future among fossils belonging to other zoological groups.

Turning now to mutations, where the varieties which succeed one another are closely related genetically, we have to consider the necessity for very careful study in distinguishing one mutation from another, as proved by recent work. In the early days of palæontological investigation, the characters utilized for the purpose of separating varieties were sufficiently obvious to be detected in single specimens, and the minute variations which have in some cases been found to mark off mutations from each other were unknown. The researches of Mr. W. Bateson on the forms of *Cardium* in the Aralo-Caspian basin, and of Dr. A. W. Rowe on the variations of *Micraster* at different horizons, have proved the value of dealing with suites of specimens of each mutation, and subjecting them to minute and accurate measurement. It is obvious that much work of a similar nature remains to be accomplished in the case of other fossil forms; and those who follow Dr. Rowe's line of research will naturally undertake the study of forms which are preserved in sufficient numbers in the fossil state. This cannot be done by the examination of museum-specimens; but specialists in the different groups of organisms must, as Dr. Rowe has done, obtain the specimens for themselves from the rocks in which they are entombed.

Another matter too often overlooked is the frequency of occurrence of individuals in a particular stratum or group of strata, and especially the relative proportions of different species in the strata. Sometimes forms are stated to be common or rare, and occasionally a more detailed division into 'very rare, rare, common, and very common' is made. But it is very desirable that such groups of strata should be studied as contain a varied fauna composed of numerous individuals of easily-identified forms, and that the proportions of the different forms which occur at different horizons should be, as far as possible, ascertained. The rich graptolite-bearing beds of the Moffat district, or those of the Llandovery age in Lakeland, would be well adapted for this purpose; and a comparison of the strata of two or three sections situated at some distance

apart should be made, in order to ascertain the changes which take place laterally as well as those which occur in the vertical succession. The task would not be easy, owing to the frequent appearance of a particular form in exceptional abundance on one bedding-plane; and for this reason, notwithstanding very detailed work, some differences would be due to the non-detection of certain of the fossils. But, notwithstanding this, it is clear that such numerical estimates would go far towards adding to our knowledge of the changes which take place in the faunas, and many now obscure points might be cleared up; in particular, we should discover whether at certain horizons a marked change in the faunas takes place with exceptional suddenness, without any obvious change in the character of the sediments to account for it.

In carrying out such a piece of work, all the lithological changes should of course be noted, and also the existence at some horizons of changes in lithological character without the presence of a bedding-plane (in the form of a plane of discontinuity marking temporary cessation of sedimentation), and at others of such planes of discontinuity severing in some places rocks of similar, and at others rocks of dissimilar, lithological characters.

Work of this nature will go far to correct many inferences which have been drawn as the result of casual collecting. It is surprising how many fossil lists of the organisms contained in the strata of our own island have been drawn up as the result of a few hours', or at most of a few days', work by the collector. Little wonder that the faunas of contemporaneous beds at considerable distances should often be judged to be very dissimilar. The Shineton fauna described by Dr. Callaway as occurring in Shropshire was rightly referred by him to the age of the Tremadoc Slates, although the fauna was very different from that of those slates at Tremadoc as then known. Recent research has proved that this particular zone of Tremadoc rocks had not then been discovered in the Tremadoc district, and its subsequent detection has shown the similarity of the fossils of that band in the Tremadoc and Shineton neighbourhoods. Consider the rich fauna of the Wenlock Limestone made known to us in a large degree by the work of Col. Fletcher, Dr. Grindrod, and others, carried on through many years. What should we have known of this fauna, if a collector had merely hammered at the rocks for a few days, as has been done in the case of so many other deposits?

The rough-and-ready methods which, in some cases, have been pursued in compiling lists of fossils of the different sediments would

not be tolerated at the present day in any other branch of science, and it is time indeed that the stratigraphical geologist should apply himself to his own branch of work with the assiduity and attention to detail which are now expected of the palæontologist in the museum.

### (6) Climatic Changes.

Of all the recent changes with which the meteorologist has to deal, the most regular are those variations of temperature which are due to extra-terrestrial causes. An area may be subjected to fog, tempest, or drought, owing to irregular meteorological changes; but, apart from these, we have constant diurnal and summer heat, constant nocturnal and winter cold. Less regular, though still, so far as we can judge from the scanty data at our disposal, recurring with some approach to constancy, are such temperature-changes as are indicated, for example, by the alternate periods of advance and retreat of glaciers.

The question naturally arises: were there not in past ages even more important cases of climatic recurrence, of which each phase may have existed through long periods of geological time? This is, at any rate, suggested by the widespread occurrence of glacial conditions in the Permo-Carboniferous Period, and by the existence in so many areas of Tertiary deposits, showing a gradual diminution of temperature from early Tertiary times to the culminating stage of cold of Pleistocene date. If such recurrence happened as the result of important extra-terrestrial changes, we should expect its effects to be more widespread than those which were caused by terrestrial changes; it is important, therefore, to collect evidence bearing upon this question. I cannot help believing that the changes noted when studying the geogram, both as regards lithological characters and faunas and floras, sometimes possess so extended a geographical range that ordinary terrestrial change is insufficient to account for them. I have again and again been struck with similarities, difficult to put into words, between the lithological characters of various Lower Palæozoic sediments from many parts of the Old and New Worlds, which would suggest the general age of the deposits, even if we could not corroborate the inference by examination of the included organisms.

We also find examples of variation of fauna occurring during shorter geological periods, which in the present state of our knowledge seem most readily explicable by climatic change, though I must



confess that these cases are merely suggestive. I discussed one of them eighteen years ago in a paper read before the Cambridge Philosophical Society,<sup>1</sup> and may be allowed to refer to it here. The Stockdale Shales of the Lake District contain bands of dark graptolite-bearing shales, interstratified with lighter mudstones in which graptolites are rare or absent. Sometimes the alteration in fauna is accompanied by change in the lithological characters of the rocks, indicating that the faunistic change is not due to an inherent tendency in the organisms to undergo variation. At other times the faunistic change seems to be unaccompanied by any noticeable difference in the lithological characters of the rocks, save such as is produced by the absence of organic material therein. This suggests that the changes which produced the succession of faunas of the different zones were due to something which did not in these cases affect the lithological characters of the rocks; and the only cause of which I can conceive is climatic variation in an area sufficiently remote from land to prevent the change from affecting the nature of the sediment supplied to the area. I had hopes of working at this subject in greater detail, but have hitherto been prevented from doing so. I believe that this work, in conjunction with that suggested previously (namely, the attempt to ascertain the variations in the proportions of the different species in successive zones), would well repay anyone who undertook it.

That the plane separating groups of rocks which are distinguished one from the other by differences in lithological characters or organic contents is not always coincident with the plane which divides a synchronously-formed group from one formed before or afterwards is well known. Let us take note of a few examples.

As regards lithological characters, we find illustrations among the Cretaceous rocks of our islands. The Gault of the south is represented in Northern Norfolk, Lincolnshire, and Yorkshire by the Red Chalk, so that anyone mapping these formations by lithological characters would draw the basal line of the Chalk beneath rocks of Albion age in the North-East of England, and beneath rocks of Cenomanian age in the South of England. Again, we find glauconitic deposits of Lower Greensand age in the North-East of England, of Gault age in the South-West, and in Northern Ireland of an age when parts of the English Chalk were being deposited. If, therefore, we could trace the Cretaceous rocks continuously from

<sup>1</sup> 'On Homotaxis' Proc. Camb. Phil. Soc. vol. vi (1887) p. 74.

Kent to Antrim, we should find a belt of sediments marked by the abundance of glauconite running obliquely to the planes which define synchronous deposits.

Turning to belts characterized by definite organisms in this same Cretaceous system, we recollect that it is maintained by Mr. Jukes-Browne that the beds of the zone of *Pecten asper* in France are of later date than those of the same zone in Britain; and Mr. Jukes-Browne, Mr. H. Woods, and Dr. W. F. Hume have shown the occurrence of a particular type of fauna at different horizons in the Upper Cretaceous rocks of the British Isles.

Many other examples might be given, but the foregoing are sufficient for our purpose.

In an ideal classification, therefore, of the sedimentary rocks we require a triple nomenclature, in order to subdivide the rocks according to lithological characters, organic contents, and periods of formation. It is true that, in some cases, the groupings based on each of these will be identical, but in others they will differ. The agreement, or want of agreement, of the groupings can only be determined as the result of detailed work.

The necessity for this triple classification has long been tacitly recognized, and has indeed been largely carried out in the case of the Mesozoic rocks, but no definite scheme of nomenclature has been adopted for the whole of the sedimentary rocks, although it is clearly required.

Such a scheme, to be acceptable, must not necessitate a violent change from the nomenclature at present in use. It is my wish to point out that the scheme which has been practically adopted in the case of the Mesozoic rocks is generally applicable to rocks of other ages, and does not demand any marked departure from the existing nomenclature.

The lithological names proposed by William Smith were, at one time, largely used as chronological names also; but, as the result of fuller work, they have been almost entirely superseded for the latter purpose by other expressions, which are, it is true, in many cases modifications of the original word: for instance, we speak of a particular lithological group as the Kimmeridge Clay, but the rocks of the age of the Kimmeridge Clay are known as Kimmeridgian. I would suggest that the names adopted in a scheme of classification of strata divided according to their ages should always end in 'ian,' the termination adopted in the case of the time-subdivisions of the Mesozoic rocks.

For the divisions founded on faunistic change, the name of a dominant organism or group of organisms should be applied, as zone of *Micraster* (sp.), zone of *Stephanoceras Humphreianum*, zone of *Monograptus gregarius*. As the term zone has been so generally used by stratigraphical geologists in the sense of fossil-zone, it would be well to use it only in this way, it being distinctly understood that the term is applied to a belt of strata characterized by some organism or organisms, without any regard to the thickness of that belt.

It has been customary to apply local names to the lithological belts, and this custom is in every way desirable. It is true that it necessitates the employment of new terms when a fresh area is worked out in detail, but the trouble thus caused is slight; whereas, if the name given in one locality be applied to another, endless confusion may arise, should it be proved that the beds to which the name is afterwards assigned are really of different age from those to which it was first given.

In illustration of these remarks, I wish to direct your attention at some length to the strata of the Ordovician system, for the classification of those rocks is still in an unsatisfactory state.

The time-divisions which I would, at present, propose to adopt for the rocks of this system are as follows :—

ORDOVICIAN	{	Ashgillian.
		Caradocian.
		Llandeilian.
		Skiddavian.

I say at present, for should modification be necessary in the future, it can be readily adopted.

In proceeding to discuss the significance of these terms and the reason for their adoption, it will be convenient to consider them *seriatim*, beginning with the oldest—namely, the Skiddavian rocks.

1. The Skiddavian Series.—In Sedgwick's final revision of the classification of the great mass of Lower Palæozoic rocks, which he studied with such success, he applied the term 'Arenig or Skiddaw Group' to the rocks which we are now considering.<sup>1</sup> I suggest the use of the term derived from the Cumbrian rather than from the Cambrian hill, because the age of the rocks of Arenig is still under discussion, while the Skiddaw Slates have yielded a rich fauna which enables us to refer the great bulk of the

<sup>1</sup> 'A Catalogue of the Collection of Cambrian & Silurian Fossils contained in the Geological Museum of the University of Cambridge' 1873, p. 19.

fossiliferous beds of those slates to this age, although even there some of the fossils may belong to rocks of earlier and later date.

Unfortunately, we are even now unable to indicate the exact position of the base of the division, for we do not know how far beds which have been assigned to it are contemporaneous with the higher Tremadocian strata of the Cambrian system. (I follow British writers in retaining the Tremadocian rocks in the Cambrian system, though many Continental geologists place them with the rocks referable to the Ordovician system, for I see no reason to depart from the classification which was originally applied.)

The graptolitic beds of Skiddavian age have been satisfactorily grouped, and I here reproduce the table drawn up by the latest worker on these beds in Britain, namely, Miss G. L. Elles,<sup>1</sup> merely substituting the name 'Skiddavian' for 'Arenig Series,' which appears in Miss Elles's paper:—

SKIDDAVIAN.	WALES.	SHROPSHIRE.	LAKE-DISTRICT.	SCANIA.
	Zone of <i>Didymograptus</i> <i>bifidus</i> .	Lower Hope Shales.	Ellergill Beds.	Zone of <i>Glossograptus</i> . Zone of <i>Phyllograptus</i> , cf. <i>typus</i> .
	Zone of <i>Didymograptus</i> <i>hirundo</i> .	Upper Mytton Flags.	Upper <i>Tetragraptus</i> - Beds.	Zone of <i>Isograptus</i> <i>gibberulus</i> .
	Zone of <i>Didymograptus</i> <i>extensus</i> .	Shelve Church Beds.		
	?	Lower Mytton Flags.	<i>Dichograptus</i> - Beds.	Zone of <i>Phyllograptus</i> <i>densus</i> . Zone of <i>Didymograptus</i> <i>balthicus</i> .
	Garth Grit?	Stiper Stones Quartzite.	Lower <i>Tetragraptus</i> - Beds.	Zone of <i>Tetragraptus</i> <i>phyllograptoides</i> .

The beds tabulated above may, then, be taken as defining the upper and lower limits of the Skiddavian Series so far as the areas mentioned are concerned, and it only remains to correlate the Skiddavian Beds of other areas with these. It is especially important that we should discover what non-graptolitic beds are their equivalents, for, as is well known, it was maintained by the late

<sup>1</sup> 'Some Graptolite-Zones in the Arenig Rocks of Wales' *Geol. Mag.* 1904, p. 199.

Dr. Hicks that certain beds in South Wales, which he grouped as Lower Arenig, were contemporaneous with the Upper Tremadoc Slates of North Wales. This is a matter which requires clearing up.

2. The Llandeilian Series.—In South Wales the plane of demarcation between Skiddavian and Llandeilian rocks is well shown, and separates the beds with *Didymograptus bifidus*, which belong to the top of the Skiddavian, from the basal Llandeilian Beds with *Didymograptus Murchisoni*.

In a paper in the 'Popular Science Review' <sup>1</sup> Dr. Hicks proposed grouping the uppermost Skiddavian and lower Llandeilian Beds as a new series, to which he gave the name of 'Llanvirn.' The fauna of this series is strongly developed in Central and North-Western Europe, although it is doubtful how far that fauna is of Llandeilian age. It may ultimately be found expedient to restrict the Skiddavian and Llandeilian groups, and to separate a Llanvirnian Series; but at present the divisions which were originally defined by Murchison and Sedgwick appear sufficient.

Murchison's Llandeilo division is perfectly-well defined, and in the typical area contains three faunas. We are enabled, therefore, to classify the Llandeilian as follows:—

LLANDEILIAN	{ Upper beds with <i>Nemagraptus</i> ( <i>Cænograptus</i> ) <i>gracilis</i> .
	{ Middle beds with <i>Asaphus tyrannus</i> .
	{ Lower beds with <i>Didymograptus Murchisoni</i> .

In the St. David's region Hicks discovered a fair number of fossils other than graptolites in the upper and lower beds, which, with the faunas described by Prof. Lapworth in the Girvan area, have given us some knowledge of the nature of the Llandeilian faunas preserved in the non-graptolitic deposits.

3. The Caradocian Series.—The term 'Bala' has been used in so many senses that it will be well in future to retain it for the lithological divisions in the Bala district. Sedgwick ultimately divided his Bala Beds into three groups, of which the lowest was the equivalent of the Llandeilo Beds, while the uppermost included strata which do not appear to be represented in the Caradoc area. The term 'Caradoc,' on the contrary, was given by Murchison to a group of rocks which are clearly separated from the Llandeilo Beds beneath, and, as above, stated, do not include

<sup>1</sup> 'The Classification of the Eozoic & Lower Palæozoic Rocks of the British Isles' Pop. Sci. Rev. n. s. vol. v (1881) pp. 302-303.

Sedgwick's Upper Bala Beds. In these circumstances the term 'Caradocian' is adopted as not likely to cause any confusion—such as arises, for instance, from the use of the term 'Lower Bala,' which may mean either the whole of the Llandeilo or the lower part of the Caradoc Series, according to the classification followed by various writers.

The plane of demarcation between Llandeilian and Caradocian strata has been clearly distinguished in various parts of Britain, in beds which yield almost exclusively graptolitic faunas, and also in those which furnish mixed faunas. It is found between beds of the former type in the Southern Uplands of Scotland, between the Glenkiln (Llandeilian) and Hartfell (Caradocian) Shales, and between beds of the latter type in the typical Shropshire area. Details concerning the classification of these beds in South Shropshire, where the beds are spoken of as the 'Chirbury Series,' will be found in a paper by Prof. Lapworth & Prof. Watts.<sup>1</sup>

In the heart of Wales the lower limit of the Caradocian has not yet been definitely settled.

In the border-region of the Lake-District Prof. Nicholson and I have given reasons for believing that there are two very well-marked faunas of Caradocian age, belonging to beds which I have elsewhere spoken of as 'the Roman-Fell Group' and 'the Sleddale Group.'<sup>2</sup> The latter fauna is so clearly that of the Bala Limestone and associated rocks of North Wales that there is no doubt as to their general contemporaneity; but the former is an older fauna, and there is some reason to suppose that it has been detected in parts of North Wales, although there it has not been definitely distinguished from the fauna of the higher Caradocian rocks.

4. The Ashgillian Series.—The line of demarcation between the Caradocian and the Ashgillian Series may be easily drawn, owing to the marked change in the faunas.

As before stated, these Ashgillian Beds correspond generally with the series to which Sedgwick gave the name 'Upper Bala,' though he never defined the exact position where the line should be drawn. In the Cambridge Catalogue of Cambrian & Silurian Fossils he says (p. 26): "'Upper Bala" comprehends the Aber Hirnant Beds above the Bala Limestone, with a peculiar set of

<sup>1</sup> 'The Geology of South Shropshire' Proc. Geol. Assoc. vol. xiii (1894) p. 297.

<sup>2</sup> 'The Coniston-Limestone Series' Geol. Mag. 1892, p. 97.

fossils ;' and, again (p. 39), Salter notes that Sedgwick's Middle Bala 'group extends a short distance, probably a couple of hundred feet, above the Bala Limestone. But it does not include the Hirnant Limestone, which is the base of the Upper Bala group.'

In view of this vagueness, it appears justifiable to draw the line between the Caradocian and the Ashgillian, in accordance with Sedgwick's statement that the Upper Bala has a peculiar set of fossils. In this case it will include the Rhiwlas Limestone and all other beds above the Bala Limestone, to the summit of the Ordovician System. It is perfectly clear that, so long ago as 1847, some member of the Geological Survey suspected from the faunas that the Rhiwlas Limestone was not the Bala Limestone ; for there is a sentence, in one of Jukes's letters of that date, which shows that some one maintained that the limestone at Creigiau Isaf was Rhiwlas and not Bala Limestone.<sup>1</sup>

By utilizing this marked contrast between the Caradocian and Ashgillian faunas we can subdivide the Ashgillian rocks of North Wales as follows :—

ASHGILLIAN	{	Hirnant Limestone.
		Shales.
		Rhiwlas Limestone.

The fauna of these Ashgillian strata is so very different from that of the Caradocian that one cannot have the least hesitation in assigning them to a different series, and as the beds are not known in the type-area of Caradocian deposits, it would be altering the signification of the term Caradocian in a marked degree to add them to the Caradocian Series.

The beds are well represented in the Lake District, and as we find the term Ashgill Beds used and defined in Sedgwick's Catalogue (p. 72)—'I arrange *Ashgill* Beds (above the Coniston Limestone) with this division,' that is the Upper Bala division,—it may be well adopted as the name of the series, for the limit drawn here between the Middle and the Upper Bala of Sedgwick is exactly that which I would desire to see adopted between the Caradocian and the Ashgillian Series.

In my paper on the Coniston-Limestone Series, to which reference has been already made, I gave some account of the development in Britain and Scandinavia of the strata of this series. In that paper the beds of Keisley were placed in the Sleddale Group, which is Caradocian ; but, after reading Mr. F. R. C. Reed's paper on the

<sup>1</sup> See 'Letters . . . of J. Beete Jukes' 1871 p. 293.

Keisley Limestone,<sup>1</sup> I quite agree with him that 'its palæontological features point to its stratigraphical position being at the base of the Upper Bala' (that is, Ashgillian).

As regards the faunas of the Ashgillian Series, the basal limestone seems everywhere to contain *Staurocephalus*, though not always in abundance. It has accordingly been referred to in Britain and Scandinavia as the '*Staurocephalus*-Limestone.' The shales above usually yield *Dalmanites mucronatus*, a form which passes into the Llandovery rocks of the Silurian system.

The Ashgillian fauna of Britain requires to be fully worked out. Its forms are found in profusion in the Bala district, in the region around Haverfordwest, in the Lake District and the Cross-Fell inlier, and probably in the Girvan district of Scotland and in the North of Ireland.

My remarks on the classification of the Ordovician strata are designed to show that, as our knowledge increases, more accurately-defined planes than those which were used for purposes of classification by the pioneers of stratigraphical geology are necessary. This involves a certain amount of change of nomenclature, but I have endeavoured to show that such change may be made without any violent alteration of the nomenclature which is at present in use.

We have time-names for the rocks of most of the great systems—as, for instance, the Olenellian, Paradoxidian, Olenidian, and Tremadocian in the Cambrian System; the Valentian, Salopian, and Downtonian in the Silurian; and the Taunusian, Coblenzian, Eifelian, and Clymenian in the Devonian. As our knowledge increases, we shall refer the beds of new areas to their places among these different series, marking periods of time, with a confidence similar to that with which we have long assigned strata of remote regions to one or other of the great systems.

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<sup>1</sup> 'The Fauna of the Keisley Limestone:—Part II' Quart. Journ. Geol. Soc. vol. liii (1897) p. 67.



February 22nd, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Edward Andrewes, B.Sc., Mining Engineer, Portmadoc (North Wales); Moses Kellow, Bryn, Croesor, Penrhyndeudraeth (North Wales); Geoffrey A. Longden, Mining Engineer, Pleasley, near Mansfield; and John Dunlop Millen, Launceston (Tasmania), were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. F. A. BATHER exhibited a series of Danish rocks<sup>1</sup> illustrating:

- (1) the share that Echinoderms may take in rock-building;
- (2) the transition from the Secondary to the Tertiary Era in the Baltic basin near Denmark;
- (3) the special conditions at the close of the Glacial Period, in the limited area where alone these rocks are now found as erratic blocks.

The specimens comprised:—(a) Fragment of a boulder from the Free Harbour of Copenhagen, consisting of rock from the zone of *Crania tuberculata*, and containing many unrolled echinoderm-fragments; it appears to have been formed in shallow water. (b) Fragment of a boulder from Langeland, consisting of rock of Paleocene age, and containing rolled fragments of Cretaceous echinoderms with shells of Tertiary molluscs; (c) Fragment of a similar boulder, showing signs of further detrition; (d) Fragment of a boulder from the island of Rügen, with echinoderm-fragments still more rolled. All these rocks appear, from the distribution of the boulders, to have been deposited in a basin of the Baltic between Scania and the islands of Rügen and Bornholm, where the Paleocene sea was shallower than on the west of Denmark.

The following communications were read:—

1. 'On the Order of Succession of the Manx Slates in their Northern Half, and its Bearing on the Origin of the Schistose Breccia associated therewith.' By the Rev. John Frederick Blake, M.A., F.G.S.

2. 'On the Wash-outs in the Middle Coal-Measures of South Yorkshire.' By Francis Edward Middleton, F.G.S.

<sup>1</sup> The rocks have been described in papers by K. A. Grönwall, Danmarks geol. Undersög. II. Række, No. 15; Medd. Dansk geol. Foren. vol. x, p. 1; and Jahrb. Preuss. geol. Landesanst. vol. xxiv, p. 420: all in 1904; also by W. Deecke, Mitth. naturwissensch. Ver. Neuvorpommern, vol. xxxi (1899) p. 67.

In addition to the specimens described on p. lxxxvii, the following specimens, maps, etc. were laid on the table :—

Rock-specimens, exhibited by the Rev. J. F. Blake, M.A., F.G.S., in illustration of his paper.

Lantern-slides, exhibited by F. E. Middleton, F.G.S., in illustration of his paper.

Geological Survey of England & Wales : Vertical Section, no. 87 : Sections of Shafts etc., in the Coal-Measures above the Hughes Vein, near Neath, Swansea, & Llanelly, by A. Strahan & E. E. L. Dixon, presented by the Director of H.M. Geological Survey.

Fifteen platinotype-photographs of Fellows of the Society (cabinet size) presented by Messrs. Maull & Fox.

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March 8th, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Albert Mayon Henshaw, Mining Engineer, Talk o'th' Hill, near Stoke-upon-Trent, was elected a Fellow of the Society.

The List of Donations to the Library was read.

Mr. ALFRED HARKER exhibited a series of photographic views illustrating the geological structure and physical features of the mountains of Skye. He remarked that the photographs were mostly taken by Mr. Abraham, of Keswick, but a few were taken by one of the officials of the Geological Survey of Scotland.

Mr. BAUERMAN congratulated the Society on the interest of this exhibit. To a large number of Fellows the locality was not much more than a name, and therefore the vivid manner in which the physical and geological features of the country had been brought before them was of extreme value.

Sir ARCHIBALD GEIKIE, in congratulating Mr. Harker on the successful completion of the arduous task on which he had been engaged for so many years among the mountains of Skye, alluded to the labours of the various observers who, from the time of Robert Jameson onwards, had been attracted to that fascinating district. More than half a century had passed away since the speaker himself first set foot on the Skye hills, and he could recall his early impression of the strangely gneiss-like aspect of the gabbros of Coruisk, though not until long after that first visit did the opportunity come to him of studying the volcanic geology in detail. It was a source of great satisfaction to him that the conclusions at which, after many years of research, he had arrived regarding the

sequence of the rocks in the south of Skye had been so completely confirmed by the much more detailed work of Mr. Harker. The admirably-constructed map on the wall, and the striking slides shown on the screen, brought the whole scenery and geology vividly before the eye, and he had to thank Mr. Harker for the very great pleasure which the exhibit had given him.

Prof. WARRS congratulated Mr. Harker and Dr. Teall, on the publication, on the 6-inch scale, of the most accurate and detailed piece of igneous-rock mapping hitherto executed in the world.

Dr. F. H. HATCH, in exhibiting lantern-slides of the 'Cullinan' diamond, said that the photographs were made by Mr. E. H. V. Melvill, to illustrate a description of the stone which Dr. Corstorphine and the exhibitor had received the permission of the Directors of the Premier Company to make, and which they proposed shortly to publish. The photographs showed the diamond from four points of view and its actual size. The stone was a portion (probably less than half) of a distorted octahedral crystal. As it now existed, the stone was bounded by portions of four original octahedral surfaces and by four cleavage-planes. The former showed in places a slight curvature, a mammillary structure, striations, and triangular pittings, while the cleavage-surfaces were distinguished by greater regularity and smoothness. The stone weighed  $3024\frac{3}{4}$  carats. Its greatest linear dimension was 4 inches. It was of remarkable purity for so large a stone, approaching 'blue-white' in colour. It was found at the beginning of the present year, in the 'yellow ground' of the Premier Mine, at a depth of 18 feet below the surface. The Premier Mine was a true 'pipe,' situated on the farm of Elandsfontein, 20 miles north-east of Pretoria (Transvaal).

Mr. A. P. YOUNG said that he wished to know whether there was marked adhesion of the matrix to any of the surfaces, and whether the exhibitor could add anything on the subject of experiments reported to prove the etching of diamond by the fused 'blue ground.'

Dr. HATCH replied that the specimen had been cleaned in the usual way with hydrofluoric acid, but there was no sign of the surface having been etched in the manner suggested.

The following communications were read:—

1. 'Observations on some of the Loxonematidæ, with Descriptions of two New Species.' By Miss Jane Donald. (Communicated by Prof. Theodore Groom, M.A., D.Sc., F.G.S.)

2. 'On some Gasteropoda from the Silurian Rocks of Llangadock (Caermarthenshire).' By Miss Jane Donald. (Communicated by Prof. Theodore Groom, M.A., D.Sc., F.G.S.)

In addition to the lantern-slides described on pp. lxxxviii & lxxxix, the following specimens and maps were exhibited :—

Specimens and casts of Silurian Gasteropoda, exhibited in illustration of the papers by Miss Jane Donald.

‘Blue Ground’ from the Premier Mine near Pretoria and from the Lace Mine (Orange-River Colony); also photographs and plans of the Cullinan Diamond, actual size, exhibited by Dr. F. H. Hatch, M.Inst.C.E., F.G.S.

Geological-Survey 6-inch Maps of part of Skye, and Sheet 70 of the Geological-Survey 1-inch Map of Scotland, exhibited by the Director of H.M. Geological Survey; also Sheet 327, Bournemouth, and Sheet 343, Swanage, printed in colours, of the 1-inch Geological-Survey Map of England, presented by the Director of H.M. Geological Survey.

Geological-Survey Map of Norway, Sheet 23 A, Voss-Christianity, 1905, presented by the Director of that Survey.

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March 22nd, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

George B. Pritchard, Lecturer on Geology, School-of-Mines Department, Working-Mens’ College, Melbourne (Victoria); T. Ernest Robertson, Professor of Mining, Transvaal Technical Institute, Johannesburg (Transvaal); and Emil Percy Turner, Mining Engineer, Ashwood, Longton (Staffordshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. ‘An Experiment in Mountain-Building: Part II.’ By the Right Hon. the Lord Avebury, P.C., F.R.S., P.S.A., For.Sec.R.A., F.G.S.

2. ‘The Rhætic Rocks of Monmouthshire.’ By Linsdall Richardson, F.G.S.

The following specimens were exhibited :—

Models made during Experiments in Mountain-Building, exhibited by the Right Hon. the Lord Avebury, P.C., F.R.S., P.S.A., For.Sec.R.A., F.G.S., in illustration of his paper.

Specimens exhibited by Linsdall Richardson, F.G.S., in illustration of his paper.

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April 5th, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Thomas Adamson, Mining Engineer, Giridih, E.I.R., Bengal (India); Malcolm Burr, B.A., F.L.S., 23 Blomfield Court, Maida Vale, W.; Thomas Crook, Assoc.R.C.S., Assistant-Geologist & Mineralogist, Imperial Institute, S.W.; William Albert Parker, 141 B Yorkshire Street, Rochdale (Lancashire); Lieut.-Colonel Bruce Morland Skinner, R.A.M.C., 68 Victoria Street, S.W.; and Herbert I. C. Turner, University College, Gower Street, W.C., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On the Divisions and Correlation of the Upper Portion of the Coal-Measures, with special reference to their Development in the Midland Counties of England.' By Robert Kidston, F.R.S.L. & E., F.G.S.

2. 'On the Age and Relations of the Phosphatic Chalk of Taplow.' By Harold J. Osborne White, F.G.S., and Llewellyn Treacher, F.G.S.

The following specimens, etc. were exhibited :—

Specimens, microscope-slides, and lantern-slides, exhibited by H. J. Osborne White, F.G.S., & Ll. Treacher, F.G.S., in illustration of their paper.

Photographs of Nan-t'ou, Hupei (China), and of Pebbles from the Nan-t'ou Formation, taken by Mr. Bailey Willis, Carnegie Expedition (1904), exhibited by Sir Archibald Geikie, Sec.R.S., F.G.S.

Photographs of the Cullinan Diamond, exhibited and presented by Edward Harker Vincent Melvill, Assoc.M.Inst.C.E.

Geological Map of Cyprus, on the scale of  $5\frac{1}{2}$  miles to the inch, with a Key to the same, by Charles Vincent Bellamy, M.Inst.C.E., F.G.S., presented by the Author.

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April 19th, 1905.

HORACE B. WOODWARD, F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Blea-Wyke Beds and the Dogger in North-East Yorkshire.' By Robert Heron Rastall, B.A., F.G.S.

2. 'Notes on the Geological Aspect of some of the North-Eastern Territories of the Congo Free State.' By Gaston Félix Joseph Preumont. (Communicated by J. Allen Howe, B.Sc., F.G.S.) With Petrological Notes by John Allen Howe, B.Sc., F.G.S.

The following specimens and map were exhibited:—

Specimens from the Dogger and Lias of North-East Yorkshire, exhibited by R. H. Rastall, B.A., F.G.S., in illustration of his paper.

Fossils from the Inferior Oolite (Dogger) of North-East Yorkshire, exhibited by R. S. Herries, M.A., V.P.G.S.

Specimens from the North-Eastern Territories of the Congo Free State, exhibited by J. A. Howe, B.Sc., F.G.S., in illustration of his and Mr. G. F. J. Preumont's paper.

Geological Survey of England & Wales:—1-inch Map, n. s., Sheet 300, Alresford (colour-printed), presented by the Director of H.M. Geological Survey.

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May 10th, 1905.

R. S. HERRIES, M.A., Vice-President, in the Chair.

Nicholas Samwell, Mining & Metallurgical Engineer, 3 Princes Terrace, Bayswater, W., was elected a Fellow of the Society.

The List of Donations to the Library was read.

The CHAIRMAN announced that the Council had resolved to award the Proceeds of the Daniel-Pidgeon Fund for 1905 to Thomas Vipond Barker, B.A.Oxon., who proposes to investigate the deposition of crystals of minerals and other substances in regular position on each other, with special reference to such groups as those of calcite, barytes, aragonite, etc.

The following communications were read:—

1. 'The Geology of Dunedin (New Zealand).' By Patrick Marshall, M.A., D.Sc., F.G.S.

2. 'The Carboniferous Limestone of the Weston-super-Mare District.' By Thomas Franklin Sibby, B.Sc. (Communicated by Dr. A. Vaughan, B.A., F.G.S.)

The following microphotographs and maps were exhibited:—

Microphotographs, exhibited by Dr. Patrick Marshall, M.A., F.G.S., in illustration of his paper.

Geological Survey of England & Wales:—1-inch Map, n. s., Sheet 316, Fareham, by W. Whitaker, C. Reid, & C. E. Hawkins (Drift); colour-printed, 1905. Presented by the Director of H.M. Geological Survey.

Geological Survey of Hungary: Agronomic map. Zone 20, Col. xxiii, Szeged & Kislelek,  $\frac{1}{75,000}$ , by P. Treitz. 1903. Presented by the Director of the Royal Hungarian Geological Institute.

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May 24th, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Igneous Rocks occurring between St. David's Head and Strumble Head (Pembrokeshire).' By James Vincent Elsdon, B.Sc., F.G.S.

2. 'The Rhætic and Contiguous Deposits of Glamorganshire.' By Linsdall Richardson, F.G.S.

3. 'On the Occurrence of Rhætic Rocks at Berrow Hill, near Tewkesbury (Gloucestershire).' By Linsdall Richardson, F.G.S.

The following specimens, etc. were exhibited:—

Rock-specimens, sections, and lantern-slides, exhibited by J. V. Elsdon, B.Sc., F.G.S., in illustration of his paper.

Specimens of rocks and fossils, exhibited by L. Richardson, F.G.S., in illustration of his papers.

Uebersichtskarte der untersuchten Thone der Länder der ungarischen Krone,  $\frac{1}{900,000}$ , von A. von Kalecsinszky, 1904, presented by the Director of the Royal Hungarian Geological Institute.

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June 7th, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

Leicester Bonner, Mining Engineer, Barkerville, Cariboo (British Columbia); Thomas Henry Cope, The Grove, Gateacre, Liverpool; Edward Jorissen, L. ès Sc., P.O. Box 2927, Johannesburg (Transvaal); Albert Jowett, Greendale, Tottington, near Bury (Lancashire); and Edward Harker Vintcent Melvill, Assoc.M.Inst.C.E., P.O. Box 719, Johannesburg (Transvaal), were elected Fellows; and Bunjirô Kotô, Ph.D., Professor of Geology in the College of Science, Imperial University of Tôkyô (Japan), was elected a Foreign Correspondent of the Society.



The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communications were read :—

1. 'The Microscopic Structure of Minerals forming Serpentine, and their Relation to its History.' By Prof. T. G. Bonney, Sc.D., LL.D., F.R.S., V.P.G.S., and Miss C. A. Raisin, D.Sc.

2. 'The Tarns of the Canton Ticino.' By Prof. E. J. Garwood, M.A., Sec.G.S.

The following specimens and maps were exhibited :—

Microscopic rock-sections and hand-specimens, exhibited by Prof. T. G. Bonney, Sc.D., LL.D., F.R.S., V.P.G.S., in illustration of the paper by himself and Miss C. A. Raisin, D.Sc.

Models of the Lake-Ritorn District, hand-specimens, microscopic rock-sections, and photographs, exhibited by Prof. E. J. Garwood, M.A., Sec.G.S., in illustration of his paper.

Geological Survey of England & Wales, 1-inch Map, n. s., Sheets 355 & 356 (Drift), Kingsbridge & Start Point, by W. A. E. Ussher, 1904, presented by the Director of H.M. Geological Survey.

Geological Survey of Sweden, Ser. *Aa*, nos. 119, 121, 124, 127, 128,  $\frac{1}{50,000}$ ; Ser. *Ac*, nos. 5 & 8,  $\frac{1}{100,000}$ ; and Ser. 1 *a*, Sheets 1 & 2, Berggrundskator,  $\frac{1}{200,000}$ , 1904. Presented by the Director of that Survey.

Carte Géologique Internationale de l'Europe, Livraison V, Sheets A VII, B VII, C VII, D VII, & F IV,  $\frac{1}{500,000}$ , 1905, presented by the Permanent Map-Committee of the International Geological Congress.

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June 21st, 1905.

J. E. MARR, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.



The following communications were read :—

1. 'The Relations of the Eocene and Cretaceous Rocks in the Esna-Aswan Reach of the Nile Valley.' By Hugh John Llewellyn Beadnell, F.G.S.

2. 'A Contribution to the Study of the Glacial (Dwyka) Conglomerate in the Transvaal.' By Edward T. Mellor, B.Sc., F.G.S.

3. 'On New Oolitic Strata in Oxfordshire.' By Edwin A. Walford, F.G.S.

4. 'The Causes of Variegation in Keuper Marls and other Calcareous Rocks.' By Gerald Tattersall Moody, D.Sc., F.C.S. (Communicated by Prof. W. W. Watts, M.A., M.Sc., F.R.S., Sec.G.S.)

The following specimens, lantern-slides, and maps were exhibited :—

Specimens exhibited by E. T. Mellor, B.Sc., F.G.S., in illustration of his paper.

Specimens, microscope-sections of Oolitic rocks, and lantern-slides exhibited by E. A. Walford, F.G.S., in illustration of his paper.

Specimens and lantern-slide exhibited in illustration of the paper by Dr. G. T. Moody, F.C.S.

Specimen of anhydrite and other rock-specimens from the Boultham Boring at Lincoln, exhibited by W. Whitaker, B.A., F.R.S., F.G.S.

Specimens of Oldbury Stone and Lower-Greensand chert from the gravel-pit at Bramble Hall, Rayleigh Hills (Essex), about 260 feet above Ordnance-datum, exhibited by A. E. Salter, D.Sc., F.G.S.

Specimens of fossiliferous ironstone from the Pliocene Sands of Netley Heath (Surrey), exhibited by W. P. D. Stebbing, F.G.S.

Carte tectonique de la Belgique et des Provinces voisines, par G. Dewalque,  $\frac{1}{500,000}$ , 1905, presented by the Author.

Geological Survey of England & Wales : 1-inch Map, n. s., Sheet 249, Newport (Drift); colour-printed, 1905. Presented by the Director of H.M. Geological Survey.

Geological Survey of Scotland : 1-inch Map, Sheet 70, Minginish (Skye), by C. T. Clough & A. Harker, 1905; and Vertical Sections, Fife Coalfield, Sheet 2a, 1 inch = 40 feet, 1904. Presented by the Director of H.M. Geological Survey.

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1. *The LEICESTER EARTHQUAKES of AUGUST 4TH, 1893, and JUNE 21ST, 1904.* By CHARLES DAVISON, Sc.D., F.G.S.  
(Read December 21st, 1904.)

[PLATE I—MAP.]

I. INTRODUCTION.

THOUGH an interval of nearly eleven years separated the Leicester earthquakes of August 4th, 1893, and June 21st, 1904, the two shocks were so closely related in their origin that it is convenient to regard them as members of a single series. The earthquake of 1893 is the subject of a former paper,<sup>1</sup> but the more recent investigation of twin-earthquakes has rendered that account incomplete. I have therefore re-examined the evidence, and, in the earlier part of the present paper, have briefly described the phenomena, in so far as the twin character of the earthquake and its connection with the earthquake of 1904 are concerned.

II. EARTHQUAKE OF AUGUST 4TH, 1893.

Time of occurrence, 6.41 p.m.; intensity, 5; centre of isoseismal 5, in lat. 52° 44' N., long. 1° 13' W. Number of records, 391, from 298 places, and 103 negative records from 97 places (Pl. I).

The curves on the map (Pl. I) represent isoseismal lines of intensities 5, 4, and 3. Of these, the first is 18 miles long, 11½ miles

<sup>1</sup> 'On the Leicester Earthquake of August 4th, 1893' Proc. Roy. Soc. vol. lvii (1895) pp. 87-95. In redrawing the isoseismal lines, some slight changes have been made. The expenses of both investigations were defrayed from grants received from the Government Research-Fund.

wide, and 161 square miles in area. Its longer axis runs from W.  $30^{\circ}$  N. to E.  $30^{\circ}$  S., and its centre is situated at a point 2 miles S.  $20^{\circ}$  W. of Loughborough. The isoseismal 4 is 46 miles long, 32 miles wide, and contains 1170 square miles. Its longer axis is directed from W.  $40^{\circ}$  N. to E.  $40^{\circ}$  S., and its distances from the isoseismal 5 are 8 miles on the north-east side and 5 miles on the south-west. The isoseismal 3, which forms the boundary of the disturbed area, is 59 miles long, 47 miles wide, and includes 2200 square miles, and its longer axis runs north-west and south-east. While, however, the two latter curves are normal, or nearly so, as regards their relative position, the isoseismal 5 shows a marked displacement towards the north-west, the distance of its centre from that of the isoseismal 4 being  $8\frac{1}{2}$  miles. Another feature of some significance is the deviation of about  $10^{\circ}$  between the directions of the axes of the two inner isoseismals.

Over a large part of the disturbed area—ranging from Burton-on-Trent to Ketton, and from Nottingham to Burbage—the shock consisted of two distinct parts, separated by an interval, the average duration of which was  $2\frac{1}{2}$  seconds. The first part was the stronger at Borrowash, Burton-on-Trent, and Uppingham; while at Ketton the two parts were regarded as approximately equal in intensity. The evidence derived from the nature of the shock is thus incomplete; but it is sufficient to show that, corresponding to each part of the shock, a distinct impulse must have taken place within the seismic focus.

Much more definite is the evidence afforded by the isoseismal lines. From the excentric position of the isoseismal 5 with respect to the isoseismals 4 and 3, we may infer that, if a series of intermediate isoseismals could be drawn, there would be a second group of curves similarly placed with regard to the south-eastern portion of the two outer isoseismals. It is evident, indeed, that these lines are merely the resultants of two pairs of such curves, approximately concentric with the geometric foci of the isoseismals as drawn on the map and coinciding with those curves towards the north-west and south-east; for there is a marked absence of observations of intensities 4 and 3 from the districts near the ends of the minor axes of the curves. The component isoseismals cannot be drawn with sufficient accuracy to justify their reproduction on the map; but, from their approximate paths, it follows that the centre of the south-eastern isoseismal 4 coincides very nearly with the village of Tugby, which is 17 miles E.  $34^{\circ}$  S. of the centre of the isoseismal 5; and that the intensity of the vibrations from the south-eastern focus died out much more slowly than that of the vibrations from the north-western focus.

Whether the north-western or the south-eastern focus was first in action is uncertain, but it is clear, from the brevity of the interval between the two parts of the shock and from the great distance between the centres of the two foci, that the interval between the occurrence of the two impulses was less than the time required for the earthquake-waves to traverse the region between

the two foci.<sup>1</sup> In this respect, the Leicester earthquake of 1893 resembles the twin-earthquakes of Hereford in 1896 and Derby in 1903 and 1904.

### III. EARTHQUAKES OF JUNE 21st, 1904.

On this day there were two undoubted earthquakes, the first and weaker at about 3.30 A.M., the second at 5.28 A.M.

#### *a.* June 21st, 1904: about 3.30 A.M.

Intensity, 3. Number of records 2, from 2 places.

The only records of this shock come from Groby and Markfield, at each of which localities a slight quiver was felt. The epicentre was probably near these places, both of which are close to the south-eastern margin of the north-western epicentre of the earthquake of 1893.

#### *b.* June 21st, 1904: 5.28 A.M.

Intensity, 5; centre of isoseismal 5, in lat.  $52^{\circ} 35' 2''$  N., long.  $0^{\circ} 59' 5''$  W. Number of records, 249, from 130 places, and 56 negative records from 44 places (map, p. 4).

#### Time of Occurrence.

The total number of records of the time is 215, 18 of which, lying between 5.25 and 5.32, are regarded by their observers as accurate to the nearest minute. The average of these estimates is slightly over 5.28 A.M., which agrees with the time given by a signalman at Lowesby station (6 miles from the epicentre).

#### Isoseismal Lines and Disturbed Area.

The continuous lines on the map (p. 4) represent isoseismal lines of intensities 5 and 4. The isoseismal 5 is 23 miles long, 17 miles wide, and 314 square miles in area, its longer axis running N.  $42^{\circ}$  W. and S.  $42^{\circ}$  E. The centre of the curve is about half-a-mile north-east of Burton Overy: its distances from the probable epicentre of the previous shock being about 12 miles, and from the south-eastern epicentre of the earthquake of 1893 (measured parallel to the isoseismal axes) about 3 miles to the north-west.

The outer isoseismal, of intensity 4, is  $33\frac{1}{2}$  miles long, 26 miles wide, and 681 square miles in area, its longer axes being directed from N.  $44^{\circ}$  W. to S.  $44^{\circ}$  E. Its distance from the isoseismal 5 is 3 miles towards the north-east, and  $5\frac{3}{4}$  miles towards the south-west.

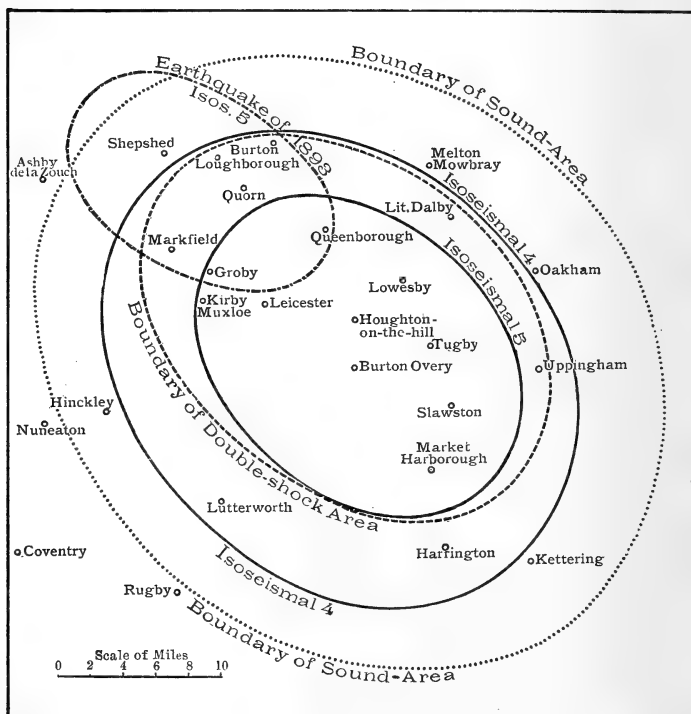
The shock was also felt at 15 places outside this isoseismal and within, though close to, the boundary of the sound-area (represented on the map by the dotted line). The disturbed area was thus 43 miles long, 36 miles wide, and covered about 1200 square miles.

<sup>1</sup> The greater intensity of the first part of the shock at Uppingham was, no doubt, due to the proximity of that place to the south-eastern focus.

## Nature of the Shock.

In the central part of the disturbed area, the shock consisted of two distinct parts, separated by a brief interval of rest and quiet. At Slawston, for example, the first and stronger part lasted 4 seconds, the interval 2 seconds, and the second part about 2 seconds; the sound was also in two parts, the first and louder

*Map illustrating the area affected by the Leicester earthquakes of June 21st, 1904.*



being compared to thunder, the other dying away after the second part of the shock, and resembling a rushing wind. Nearer the boundary of the disturbed area, as, for instance, at Harrington, the shock consisted of one continuous series of vibrations, 3 seconds in duration, increasing in intensity to a single maximum and then decreasing, and accompanied by a sound like the rumbling of a passing waggon.

The relative intensity of the two parts of the shock is given in 9 records. At Queniborough or Queenborough, according to two observers, the parts were roughly equal in intensity; at 7 other places Burton Hall, Kirby Muxloe, Leicester, Little Dalby, Lowesby,

Quorn, and Slawston) the first part is invariably described as the stronger. The interval between the parts is in every case estimated at 2 seconds.

The boundary of the area within which the double shock was felt is represented on the map (p. 4) by a broken line. It is 29 miles long,  $20\frac{1}{2}$  miles wide, and includes an area of 464 square miles; its axis is nearly parallel to those of the isoseismal lines, running from N.  $40^{\circ}$  W. to S.  $40^{\circ}$  E. The centre of the curve is about half-a-mile south-west of Houghton-on-the-Hill, in lat.  $52^{\circ} 37.1' N.$ , long.  $1^{\circ} 0.8' W.$ , or  $2\frac{1}{2}$  miles north-north-west of the centre of the isoseismal 5. As the boundary of the double-shock area is close to the isoseismal 5 towards the south and east, and to the isoseismal 4 towards the north and west, it cannot coincide with an isoseismal line corresponding to an intensity between 5 and 4. Thus, while the dotted line represents the boundary of the disturbed area of the first part of the shock, and the broken line that of the second part, it is evident that the foci of the two parts were not coincident, but, at the same time, were not completely detached. The earthquake may therefore be described as a double one, rather than as a twin-earthquake.

### Sound-Phenomena.

As already mentioned, the boundary of the sound-area (represented by the dotted line in the map, p. 4) coincides approximately with that of the disturbed area. The district is too small, and the number of records insufficient, for the construction of isacoustic lines; but it is evident, from the descriptions given, that the sound was unusually loud within a central area bounded approximately by the isoseismal 5, which is very nearly concentric with the boundary of the sound-area. The sound was, however, heard by nearly all observers close up to the latter boundary; for the percentage of audibility was 97 over the whole area, 98 within the isoseismal 5, 96 between the isoseismals 5 and 4, and 93 between the isoseismal 4 and the boundary of the sound-area.

The sound was compared to passing traction-engines, etc., in 62 per cent. of the records, to thunder in 17 per cent., wind in 4, loads of stone falling in 7, the fall of a heavy body in 5, explosions in 4, and to miscellaneous sounds in 1 per cent. There is the usual tendency towards smoothness and monotony in the sound with increasing distance from the origin. Within the isoseismal 5, the percentage of comparisons to passing traction-engines, etc., is 52, 71 between the isoseismals 5 and 4, and 76 between the isoseismal 4 and the boundary of the sound-area. For thunder, the corresponding percentages are 20, 14, and 14.

In the following table (p. 6), the figures in the columns headed *p*, *c*, and *f* indicate the number of records per cent. in which the beginning or end of the sound preceded, coincided with, or followed, the corresponding epoch of the shock; those in the columns headed *g*, *e*, and *l* indicate the number of records per cent. in which the

duration of the sound was greater than, equal to, or less than, that of the shock:—

	BEGINNING.			END.			RELATIVE DURATION.		
	<i>p</i>	<i>c</i>	<i>f</i>	<i>p</i>	<i>c</i>	<i>f</i>	<i>g</i>	<i>e</i>	<i>l</i>
Within isoseismal 5 .....	70	23	7	10	51	39	73	27	0
Between isoseismals 5 and 4...	57	39	4	7	71	21	51	46	3
Between isoseismal 4 and } boundary of sound-area. }	50	25	25	0	56	44	29	43	29
Whole sound-area .....	62	31	8	8	61	32	58	38	4

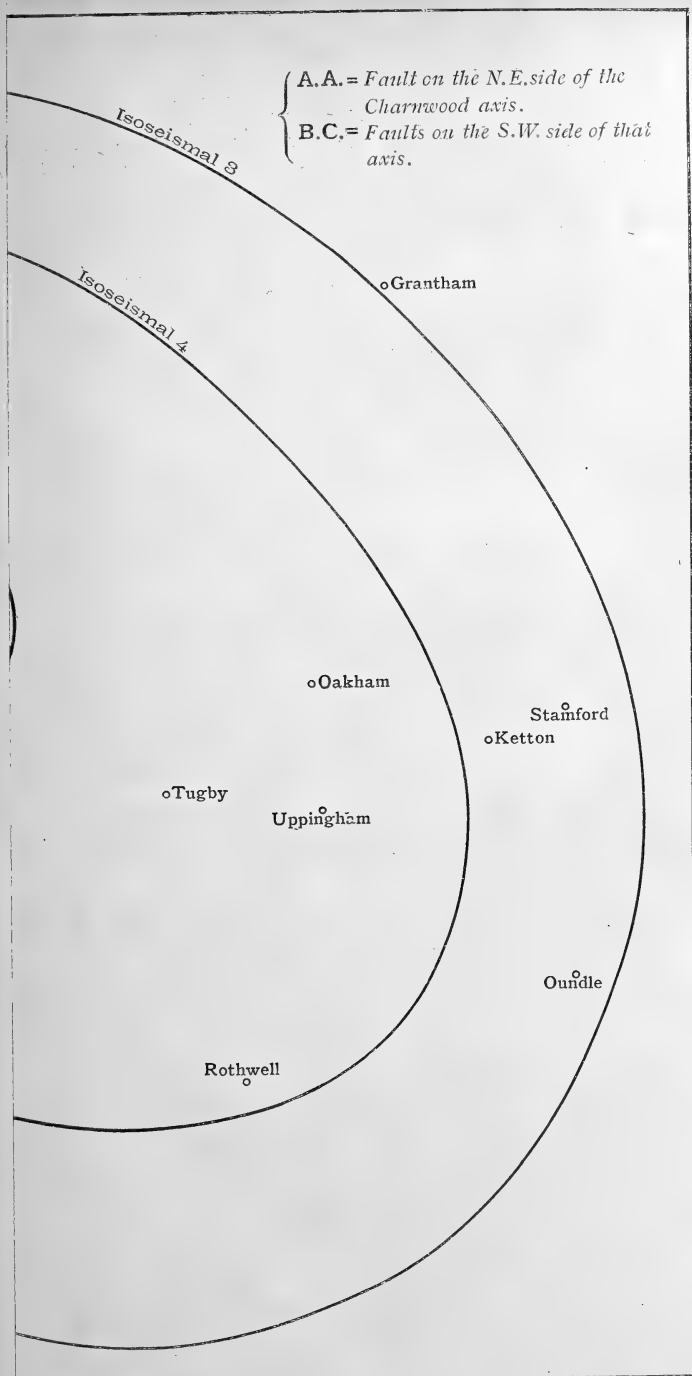
#### IV. ORIGIN OF THE EARTHQUAKES.

Taking first the earthquake of 1893, we obtain from the seismic evidence the following elements of the originating fault in the neighbourhood of the north-western focus:—(1) the mean direction of the fault is from W.  $30^{\circ}$  N. to E.  $30^{\circ}$  S.; (2) the hade is to the north-east; and (3) the fault-line passes a short distance to the south-west of the centre of the isoseismal 5, or about 1 or 2 miles to the south-west of Woodhouse Eaves. For the south-eastern focus, the elements are less clearly defined:—(1) the mean direction of the fault lies between that given above and north-west to south-east; (2) the hade is to the south-west; and (3) the fault-line passes a short distance to the north-east of the centre of the isoseismal 4 corresponding to the south-eastern focus, or not far from Tugby. These two sets of conditions are consistent with the existence of a single fault, in which the direction of hade changes in a district about midway between Markfield and Tugby.

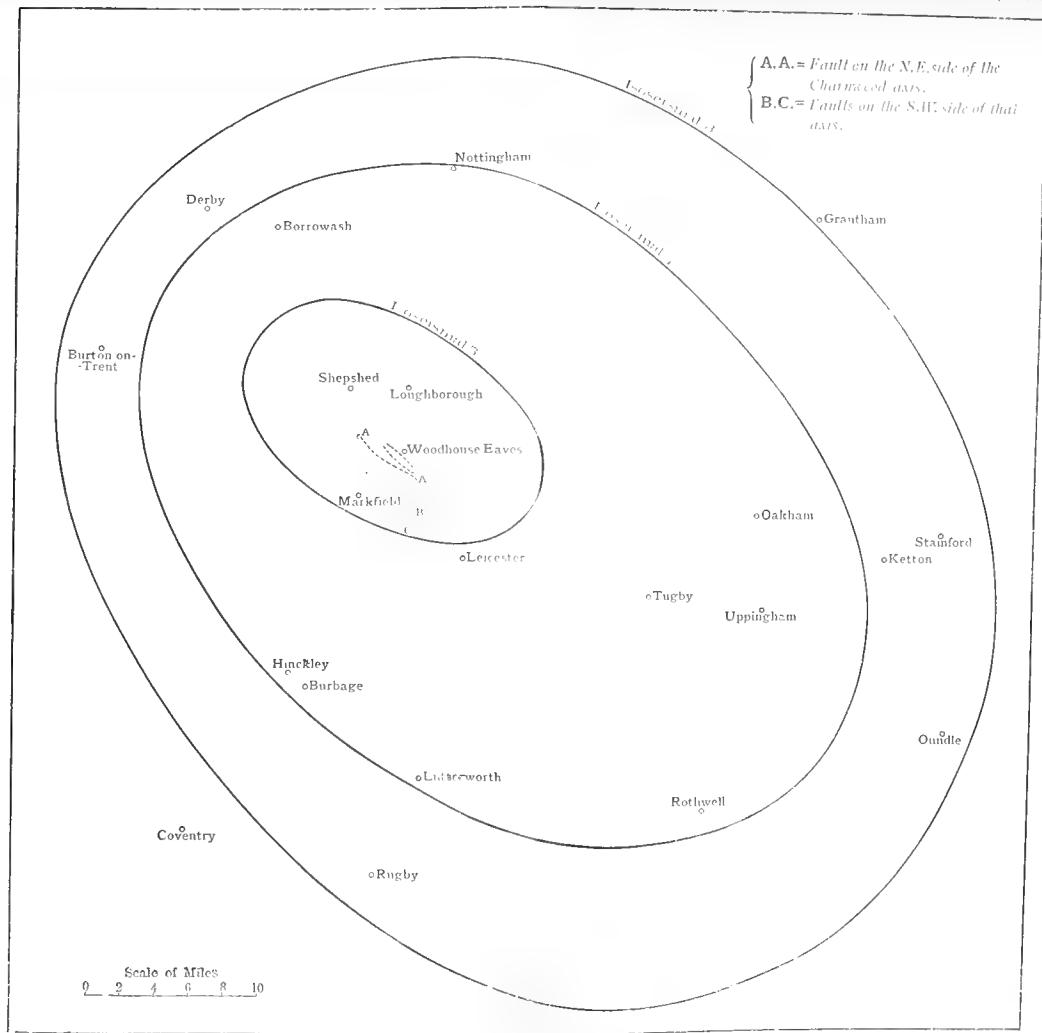
It may be remarked that this change of hade furnishes an explanation of the divergence of the axes of the resultant isoseismal lines of Pl. I. For, at the north-western focus, the isoseismal 4 diverges farther to the north-east than in the opposite direction; while, at the south-eastern focus, it diverges farther to the south-west than to the north-east. Thus, the axis of the resultant isoseismal 7 should be tilted more towards the north-west; and the same should hold true of the resultant isoseismal 3.

Again, for the principal earthquake of 1904, the elements of the earthquake-fault are:—(1) the mean direction of the fault is from W.  $42^{\circ}$  N. to E.  $42^{\circ}$  S.; (2) the hade is to the south-west; and (3) the fault-line passes a short distance to the north-east of the centre of the isoseismal 5, and therefore not far from Tugby. It is thus probable that the earthquakes of 1893 and 1904 originated in one and the same fault.









MAP ILLUSTRATING THE AREA AFFECTED BY THE LEICESTER EARTHQUAKE OF AUGUST 4TH, 1893.



The faults of Charnwood Forest have been mapped by Prof. Watts, F.R.S.,<sup>1</sup> to whom I am indebted for information on the geological structure of the district. In Pl. I, the more important strike-faults are reproduced from Prof. Watts's map, the transverse faults of later date being omitted, for the sake of simplicity. The faults on the north-east side of the Charnwood anticlinal axis probably hade to the north-east, and those on the south-west side in the opposite direction. In Pl. I, the former are indicated by broken lines, and the latter by dotted lines.

The fault which satisfies the seismic conditions most closely is that marked A in Pl. I. Its mean direction in the neighbourhood of Woodhouse Eaves is W.  $27^{\circ}$  N. and E.  $27^{\circ}$  S., it hades in all probability to the north-east, and it passes about 2 miles to the south-west of the centre of the isoseismal 5. Owing to the covering of Triassic rocks, it cannot be traced farther to the south-east than the village of Cropston; but there is no reason for supposing that it dies out at that point. Assuming, then, that the fault referred to extends to the neighbourhood of Tugby, trending there more nearly in a south-easterly direction, I will now trace briefly the history of the recent movements.

In 1893, the displacements in the two foci took place almost simultaneously and apparently in opposite directions, the interfocal region remaining stationary or nearly so. The centres of the foci were about 17 miles apart; and it is clear, from the more rapid decline in intensity from the north-western epicentre, that the corresponding focus was situated at a less depth than the other.

One effect of the double slip was to cause an increase of stress in the regions of the fault-surface bordering the margins of both foci, the greatest accession of effective stress being experienced by the interfocal portion of the fault. It is probable that the earlier slip in 1904 took place in or near the south-eastern margin of the north-western focus of 1893; but it may have been caused by a small slip along one of the faults marked B & C in Pl. I. Two hours later, this was followed by a double (not a twin) slip in or near the north-western margin of the south-eastern focus; and, judging from the rapid decline in the intensity of the shock, at a less depth than either of the foci of 1893. The second part of this double slip showed a farther migration (of 2 or 3 miles) towards the north-west, and a still closer approach to the surface of the earth.

#### EXPLANATION OF PLATE I.

Map illustrating the area affected by the Leicester earthquake of August 4th, 1893, on the approximate scale of 8 miles to the inch.

<sup>1</sup> Proc. Geol. Assoc. vol. xvii (1902) pl. xix.

2. *The DERBY EARTHQUAKES of JULY 3RD, 1904.* By CHARLES DAVISON, Sc.D., F.G.S. (Read December 21st, 1904.)

[PLATE II—MAP.]

I. INTRODUCTION.

BETWEEN the Derby earthquakes of March 24th, 1903, and July 3rd, 1904, there exist several points of intimate resemblance. The isoseismal lines of the two shocks, when drawn on one map, are so closely related that they might be the isoseismals of a single earthquake; both earthquakes were twins; the two epicentres in 1904 were nearly or quite coincident with those in 1903; and both earthquakes were followed by an after-shock, originating for the most part in the interfocal region of the fault. The points in which they differ are of little consequence. The intensity of the shock of 1903 was greater than that of the shock of 1904; the impulses at the two foci were approximately of the same strength in 1903, and of unequal strength in 1904; they occurred at the same instant on the former occasion, while, on the latter, they were separated by a brief interval of time.

The principal shock of 1903 occurred on a weekday at 1.30 P.M., that of 1904 at 3.21 on a Sunday afternoon. Thus, although of less intensity, the recent earthquake was felt and heard over a much wider area than its predecessor. There was at the time practically no traffic in the streets, and many of the observers (especially of those at a great distance from the centre) were lying down—conditions that favoured the observation of the earthquake in places at which, on an ordinary occasion, it would have passed totally unperceived.<sup>1</sup>

There were at least three earthquakes in the series of 1904, namely:—

- (a) July 3rd, 2.28 P.M.
- (b) July 3rd, 3.21 P.M. (Principal earthquake.)
- (c) July 3rd, 11.8 P.M.

In addition to these, disturbances resting on the authority of a single record were reported at the following times:—

July 3rd, 3.15 P.M.: Tissington.—Two persons, in one room, thought that they heard thunder.

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<sup>1</sup> I have to offer my best thanks to the very numerous observers who have placed their accounts at my disposal; to the editors of many newspapers who have given a wide circulation to my requests for information; and not least to those who on this, as well as on the former, occasion have been so kind as to collect records from other observers. Mr. H. H. Arnold-Bemrose has again aided me materially in this way, as have also Sir John G. N. Alleyne, Bart.; Mr. W. Wells Bladen, honorary secretary of the North Staffordshire Field-Club; Mr. W. F. Blay, of Wallsall; Mr. J. E. Bolton, of Eckington; Mr. W. J. Butcher, headmaster of the Grammar-School, Ashbourne; Mr. J. Clark, of

July 3rd, 3.23 P.M. : Dalbury Lees.—A low distant rumbling, as of thunder.

July 3rd, 4.20 P.M. : Grindon.—A heavy rumbling, without any attendant shock.

July 4th, about 1.30 A.M. : Matlock Bath.—A slight shock.

July 4th, about 6 A.M. : Wirksworth.—A slight shock.

## II. FORE-SHOCK.

### *a.* July 3rd, 2.28 P.M.

Intensity, 3. Number of records, 5, from 5 places.

A slight quivering was felt at Ambergate, Cromford, Matlock Bath, Mayfield, and Wirksworth (see map, p. 16). At Ambergate, a noise like a loud peal of thunder accompanied the tremor. Mayfield is about a mile south-west of Ashbourne. The other four places, however, are close to the north-eastern or Wirksworth epicentre of the principal earthquake, and the shock probably originated in the corresponding focus.

## III. THE PRINCIPAL EARTHQUAKE. (Pl. II.)

### *b.* July 3rd, 3.21 P.M.

Intensity, 7; centre of isoseismal 7, lat.  $53^{\circ} 0' 4''$  N., long.  $1^{\circ} 41' 6''$  W. Number of records, 1467, from 653 places, and 46 negative records from 44 places.

### Time of Occurrence.

Excluding approximate estimates, the total number of records of the time is 737. Of these, 113 are regarded by their observers as accurate to the nearest minute. The average of all the latter is  $3^h 21^{\frac{1}{4}}m$  P.M., and as the averages of the different zones included between successive pairs of isoseismals do not differ from this by more than a minute, it is probable that the time of occurrence at the epicentre was very nearly 3.21 P.M.

### Isoseismal Lines and Disturbed Area.

The five continuous curves on the map of the earthquake (Pl. II) are isoseismal lines of intensities 7 to 3, the broken-and-dotted lines referring to the earthquake of March 24th, 1903.

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Waterhouses, near Ashbourne; Mr. T. Gledhill, of Dronfield; Mr. C. W. Groves, of Risley; Mr. S. E. Howse, of Ambergate; Mr. A. V. Jones, of Church Broughton; Mr. T. W. Learoyd, of Rostherne, near Knutsford; the Rev. C. Price, of Denstone College; Mr. S. Steele, of Chesterfield; Mr. P. K. Tollit, headmaster of the Grammar-School, Derby; Miss A. C. Tute, headmistress of the High School for Girls, Derby; and Mr. W. M. Wilson, headmaster of the Higher Grade School, Hanley. By kindly writing on my behalf to the local press, Mr. Arnold-Bemrose has also prompted the communication of many valuable records. The expenses of the investigation were defrayed from a grant received from the Government Research-Fund.

The isoseismal 7 is approximately circular in form,  $7\frac{1}{4}$  miles in diameter, and 41 square miles in area. Its centre lies about  $1\frac{1}{2}$  miles east of Ashbourne in lat.  $53^{\circ} 0' 4''$  N., long.  $1^{\circ} 41' 6''$  W. The next isoseismal, of intensity 6, is roughly an ellipse, 37 miles long, 27 miles wide, and 80.4 square miles in area; the direction of its longer axis is N.  $31^{\circ}$  E. and S.  $31^{\circ}$  W., or very nearly parallel to the axis of the isoseismal 7 of the earthquake of 1903. The distance between the isoseismals 7 and 6 is 12 miles on the north-west side and 8 miles on the south-east. The most important feature in the two curves is, however, their excentricity: the distance between the centres of the two curves in the direction of the longer axis being about 2 miles. In the neighbourhood of Matlock Bath, there is another maximum of intensity 7 or nearly 7. The observations are insufficient to draw a second isoseismal in that district; but it is clear that, if the isoseismal corresponding to an intensity between 7 and 6 could be drawn, it would consist of two detached portions, one concentric with the isoseismal 7, the other not far from Wirksworth and Matlock Bath, their centres being separated by a distance of 6 or 7 miles. Thus, the two epicentres of 1904 are approximately coincident with those of the previous year.

The isoseismal 5 is the last which retains any trace of an elongated form. It is 72 miles long, 65 miles wide, and contains 3600 square miles; its distance from the isoseismal 6 is 21 miles on the north-west and 17 miles on the south-east side. The next two isoseismals are very nearly circles, the isoseismal 4 being 114 miles long from north-east to south-west, 113 miles wide, and about 10,120 square miles in area; the isoseismal 3, which forms the boundary of the disturbed area, is 181 miles long from north-east to south-west, 179 miles wide, and about 25,000 square miles in area. Observations were also made at a few places outside the latter isoseismal, at Aisgill, Appleby, Beckfoot, and Mallerstang in Westmorland; at Bridlington, on the east coast of Yorkshire; and at Long Whittenham, near Abingdon, in Berkshire.

Comparing the dimensions just given with those for the earthquake of 1903, we see that the isoseismals 7 to 4 of that earthquake are all larger than those for the earthquake of 1904; in 1903, a few buildings sustained slight injury over an area of 112 square miles, while, in 1904, there was practically no damage to property. On the other hand, the earthquake of 1904, owing to its occurrence on a Sunday afternoon, could be traced to a much greater distance, its disturbed area being about double of that of the earthquake of 1903.

#### Nature of the Shock.

In 1903, the twin-character of the earthquake was clearly defined; it was recognized by two out of every three observers, and was perceptible close to the boundary of the disturbed area. In 1904, only one out of five observers recorded the existence of two parts or



two maxima, and this was no doubt due to the incomplete separation of the two parts, an intermediate tremor being observed within the central area. Thus, at Ashbourne ( $1\frac{1}{2}$  miles from the centre of the isoseismal 7), the shock consisted of a single series of vibrations, which increased in intensity to a maximum, and then died away; at Sudbury (about 9 miles to the south), there were two such maxima connected by weaker tremulous motion; at Birmingham (37 miles distant), two series of vibrations were felt, the first being distinctly stronger, the second series a mere shudder. The intermediate tremor was perceptible as far as Farnsfield near Southwell (27 miles from the centre); while the twin-shock was felt to the north at Bradford (54 miles), to the west at Ellesmere (50 miles), to the south at Stourport (52 miles), and to the east at Hough near Grantham (44 miles), or over an area of roughly 8000 square miles in extent.

This area is, however, traversed by a band within which the two parts of the shock were superposed. It is difficult to trace the boundaries of this band with accuracy, owing to the continuity of the shock within the central district; but the course of its median line probably does not differ much from that indicated by the broken-and-dotted line on the map (Pl. II), especially towards the south-east of the epicentre. This band differs in two respects from that traced for the earthquake of 1903. In that case, the band was rectilinear and about 5 miles in width; in the earthquake of 1904, it was hyperbolic in form, the concavity of the curve facing the south or south-west, and the width of the band is greater towards its extremities, being 15 or 16 miles at a distance of 30 miles from the centre. It will be noticed that the median line passes a short distance to the north-east of the centre of the isoseismal 7.

It is obvious from the distance to which the twin-shock was perceptible that there was some, although not much, difference between the intensities of the two parts. This conclusion is also borne out by the observations on the relative intensity of the two series or maxima. To the south-west of the hyperbolic band, 49 observers regarded the first part as the stronger, 9 the second, while 2 thought them roughly equal in intensity; to the north-east of the hyperbolic band, the corresponding figures are 20, 10, and 1. On the south-west side, however, 3 observers, and on the north-east side 8 observers, were doubtful as to the order of intensity. We may, I think, conclude from these figures that, while the first part was generally the stronger all over the disturbed area, the inequality was less on the north-east, than on the south-west, side of the hyperbolic band.

Outside the hyperbolic band, the length of the interval between the two parts varied from 1 to 4 seconds. The average of 75 estimates is 2.1 seconds, and the average is practically uniform throughout the disturbed area, being 2.2 seconds within the isoseismal 6, 2.0 seconds between the isoseismals 6 and 5, and 2.1 seconds outside the latter isoseismal.

### Origin of the Double Shock.

There can be no doubt, from these observations, that the two parts of the shock originated in two foci lying along a line directed approximately from N.  $31^{\circ}$  E. to S.  $31^{\circ}$  W. A slight movement, however, took place in the intermediate region, sufficient to cause the tremulous motion felt between the two principal parts of the shock. If the impulses had taken place simultaneously, the two series would, as in 1903, have been superposed along a rectilinear band. As it is, the curvature of the hyperbolic band towards the south-western focus shows that the vibrations from the north-eastern focus travelled farther than those from the south-western focus before the two series coalesced. In other words, although the two impulses were nearly simultaneous, the north-eastern focus was in action a short time, perhaps a second or less, before the other.

In the present case, the positions of the two epicentres can be determined more accurately than in the earthquake of 1903. The south-western epicentre must coincide very nearly with the centre of the isoseismal 7, that is, it must be about  $1\frac{1}{2}$  miles east of Ashbourne. The north-eastern epicentre probably lies near Wirksworth or Matlock Bath, and about 6 or 7 miles from the other.

Corroborative evidence of these determinations is afforded by the observations on the apparent direction of the shock. The sense of direction is more appreciable in houses in which the principal walls are at right angles to the direction of the epicentre; and it was found, in the case of the Hereford earthquake of 1896, that the average of a large number of observed directions, rough though they may be, points very nearly to the epicentre. For the recent Derby earthquake, it is possible to determine such average directions for two districts, one around Derby and the other around Nottingham, these two towns lying close to, but on opposite sides of, the hyperbolic band. In the Derby district, the mean direction is from W.  $37^{\circ}$  N., or exactly in a line from the centre of the isoseismal 7; in the Nottingham district, the mean direction is from W.  $39^{\circ}$  N., and, produced backwards, this line passes through a point 3 miles west of Wirksworth.

Lastly, the existence of the isoseismal 7 around the south-western epicentre and the practical absence of such a curve from the north-eastern epicentre lead to the conclusion that the impulse at the south-western focus was stronger, though not much stronger, than the impulse at the north-eastern focus. Consequently, on the south-west side of the hyperbolic band, the first part of the shock was the stronger; on the north-east side, the first part was as a rule the stronger, owing to the proximity of the north-eastern focus from which the first vibrations arrived.

### Seismographic Records.

The seismographic records of the earthquake are of little interest, and do not add to our knowledge of its nature. Mr. W. E. Plummer,

director of the Liverpool Observatory at Bidston, near Birkenhead, informs me that, although the shock was felt by many persons there, the trace of the Milne seismograph shows but the slightest disturbance at 3<sup>h</sup> 18·8<sup>m</sup> P.M. In Birmingham, there was apparently no movement of the Omori horizontal pendulum, and only a minute displacement of the pointer of the Ewing duplex pendulum. The absence of a clearer record is probably due to the comparative weakness of the original disturbance, to the irresponsiveness of long-period horizontal pendulums to rapid vibrations, and, in the case of Birmingham, to the fact that the direction of the epicentre lies very nearly in the plane of the pendulum.

### Isacoustic Lines and Sound-Area.

In drawing the isacoustic lines for the earthquake of 1903, the whole area was divided into squares by north-to-south and east-to-west lines 10 miles apart. I have made use of the same squares for the recent shock, but have calculated the percentage of audibility corresponding to the corners of these squares, making use of the records within the four contiguous squares. In this way a larger number of observations is at our disposal, the only effect of such a treatment being to smooth away local inequalities in the resulting curves. Notwithstanding this advantage, only one isacoustic line, corresponding to a percentage of 80, can be satisfactorily drawn. This is represented by the irregular dotted line on the map (Pl. II). Its peculiar form, especially the branches to the west and south-east, is evident at once. In the former direction, the number of records is too small to complete the curve, and its course may not be quite accurately laid down, but the branch evidently extends some distance farther towards the west. For the south-eastern branch, the observations are more numerous, and it will be noticed that it lies almost exactly along the course of the median line of the hyperbolic band. The explanation of this peculiarity, of course, is that the sound-waves from the two foci coalesced along the hyperbolic band, and were therefore audible to a larger number of observers. From the study of the sound-phenomena, we are therefore again led to the conclusion that the north-eastern focus was in action slightly before the other. With regard to the less-pronounced expansion of the curve towards the north, I can offer no satisfactory explanation.

With a few isolated exceptions, the sound was heard within the area bounded by the outer dotted line in Pl. II, a line which in no place deviates more than  $4\frac{1}{2}$  miles from the isoseismal 4, overlapping that curve towards the east, south, and west, but not extending quite so far towards the north. Its dimensions are 121 miles from north-west to south-east, and 113 miles from north-east to south-west, and its area covers about 10,700 square miles. The exceptional records come from Branston Green (13 miles to the north of the boundary), Lytham (21 miles to the north-west)

Clunbury (6 miles to the south-west), and Wormleighton, Wroxton, and Brockworth (respectively 4, 11, and 27 miles to the south).

Though the sound-area is greater than in 1903, owing probably to the conditions at the time of occurrence, the percentage of audibility is somewhat less. Within the isoseismal 7, 94 per cent. of the observers heard the earthquake-sound; in the zone between the isoseismals 7 and 6, the percentage of audibility was 93; between the isoseismals 6 and 5, 79; between the isoseismals 5 and 4, 56; and outside the isoseismal 4, 38. The want of parallelism between the isacoustic line of percentage 80 and the boundary of the sound-area is probably due to the rapid decline in audibility as the latter curve is approached.

### Nature of the Sound.

The total number of descriptions of the earthquake-sound is 812. In 45 per cent. of these, the sound is compared to passing traction-engines, motor-cars, etc., in 26 per cent. to thunder, in 15 to wind, in 5 to loads of stones falling, in 4 to the fall of a heavy body, in 2 to explosions, and in 2 per cent. to miscellaneous sounds.

The variation in the nature of the sound with the distance is shown in the following table (I), in which the figures are percentages of comparison to the different types for each of the districts mentioned:—

TABLE I.	Passing vehicles.	Thunder.	Wind.	Loads of stones falling.	Fall of a heavy body.	Explosions.	Miscellaneous.
Within isoseismal 7 .....	39	41	0	9	2	9	0
Between isos. 7 and 6 ...	52	28	9	8	2	1	0
"      " 6   " 5 ...	44	24	19	3	5	3	2
"      " 5   " 4 ...	35	24	25	4	4	2	6
Outside isoseismal 4 .....	40	33	27	0	0	0	0

The most noticeable variation is the increase with distance in the proportion of comparisons to the smooth and monotonous type of wind.

### Time-Relations of the Sound and Shock.

In the following table (II, p. 15), the letters *p*, *c*, and *f* indicate the number of records per cent. in which the beginning or end of the sound preceded, coincided with, or followed, the corresponding epoch of the shock; the letters *g*, *e*, and *l* show the number of records per cent. in which the duration of the sound was greater than,

equal to, or less than, that of the shock. The last line of the table gives the percentages for the Derby earthquake of 1903:—

TABLE II.	BEGINNING.			END.			RELATIVE DURATION.		
	<i>p</i>	<i>c</i>	<i>f</i>	<i>p</i>	<i>c</i>	<i>f</i>	<i>g</i>	<i>e</i>	<i>l</i>
Within isoseismal 7 .....	70	30	0	7	47	47	71	29	0
Between isoseismals 7 and 6 .....	62	32	5	24	52	24	51	39	10
"      "      6 " 5 .....	68	24	8	12	53	35	73	25	2
"      "      5 " 4 .....	70	24	6	28	43	28	70	9	22
Whole sound-area .....	65	29	6	18	51	31	62	31	7
"      "      of the earthquake of 1903	57	37	7	21	55	24	46	46	9

For the epoch of maximum intensity, the number of records is only 37. The epoch when the sound was loudest preceded that when the shock was strongest in 30 per cent. of the records, coincided with it in 62, and followed it in 8 per cent.

The chief result of the foregoing table is the rough approach to uniformity for the different zones, whatever their distance from the epicentre. If the sound-waves travelled more rapidly than those of larger amplitude, we should expect to find an increase with distance in the observations of the sound before the shock, and a decrease in those of the sound after the shock. Except in the central area, in which both fore-sound and after-sound would naturally be more sensible, there is no distinct trace of such variation.

#### IV. AFTER-SHOCK.

##### *c.* July 3rd, 11.8 P.M.

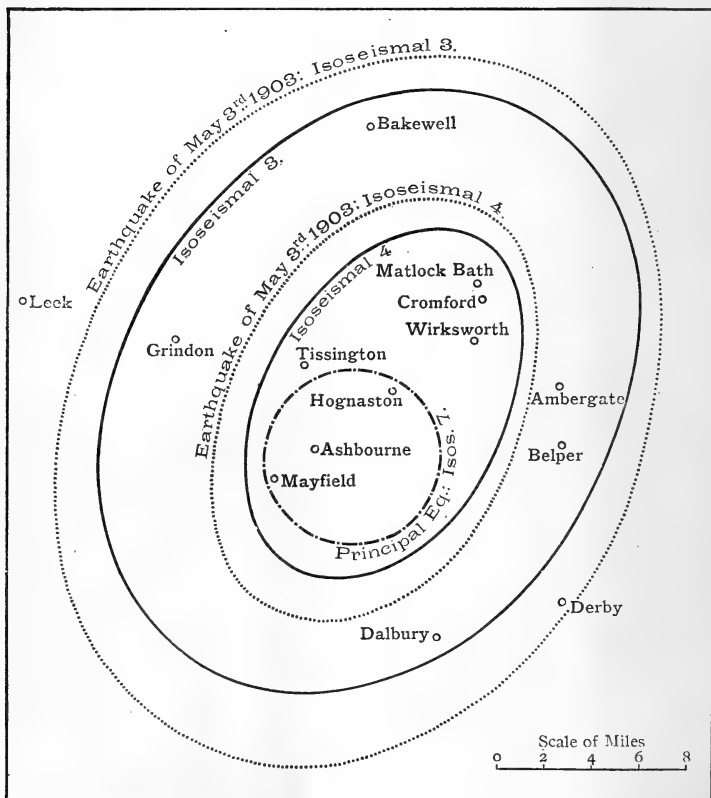
Intensity, 4; centre of isoseismal 4, in lat.  $53^{\circ} 2' 8''$  N., long.  $1^{\circ} 39' 5''$  W. Number of records, 76, from 42 places, and 2 negative records from 2 places (map, p. 16).

In the map of this after-shock (p. 16), the continuous lines represent the isoseismals 4 and 3, the dotted lines are the corresponding isoseismals for the after-shock of May 3rd, 1903; the broken-and-dotted line is the isoseismal 7 of the principal earthquake of 1904.

The isoseismal 4 is 16 miles long, 10 miles wide, and contains 125 square miles. Its centre is about half-a-mile south-west of Hognaston, and the direction of its longer axis about N.  $27^{\circ}$  E. and S.  $27^{\circ}$  W. The course of the isoseismal 3 is somewhat doubtful towards the north and south, but the error in either case is probably less than a mile. As drawn, it is 27 miles long, 20 miles wide,

and contains 425 square miles. The distance between the two isoseismals is 6 miles on the north-west, and  $4\frac{1}{2}$  miles on the south-east, side. The shock and sound were also observed, though very faintly, at Derby,  $1\frac{1}{2}$  miles south-east of the isoseismal 3, and at Leek,  $4\frac{1}{2}$  miles west of the same curve.

*Map illustrating the area affected by the after-shock of July 3rd, 1904.*



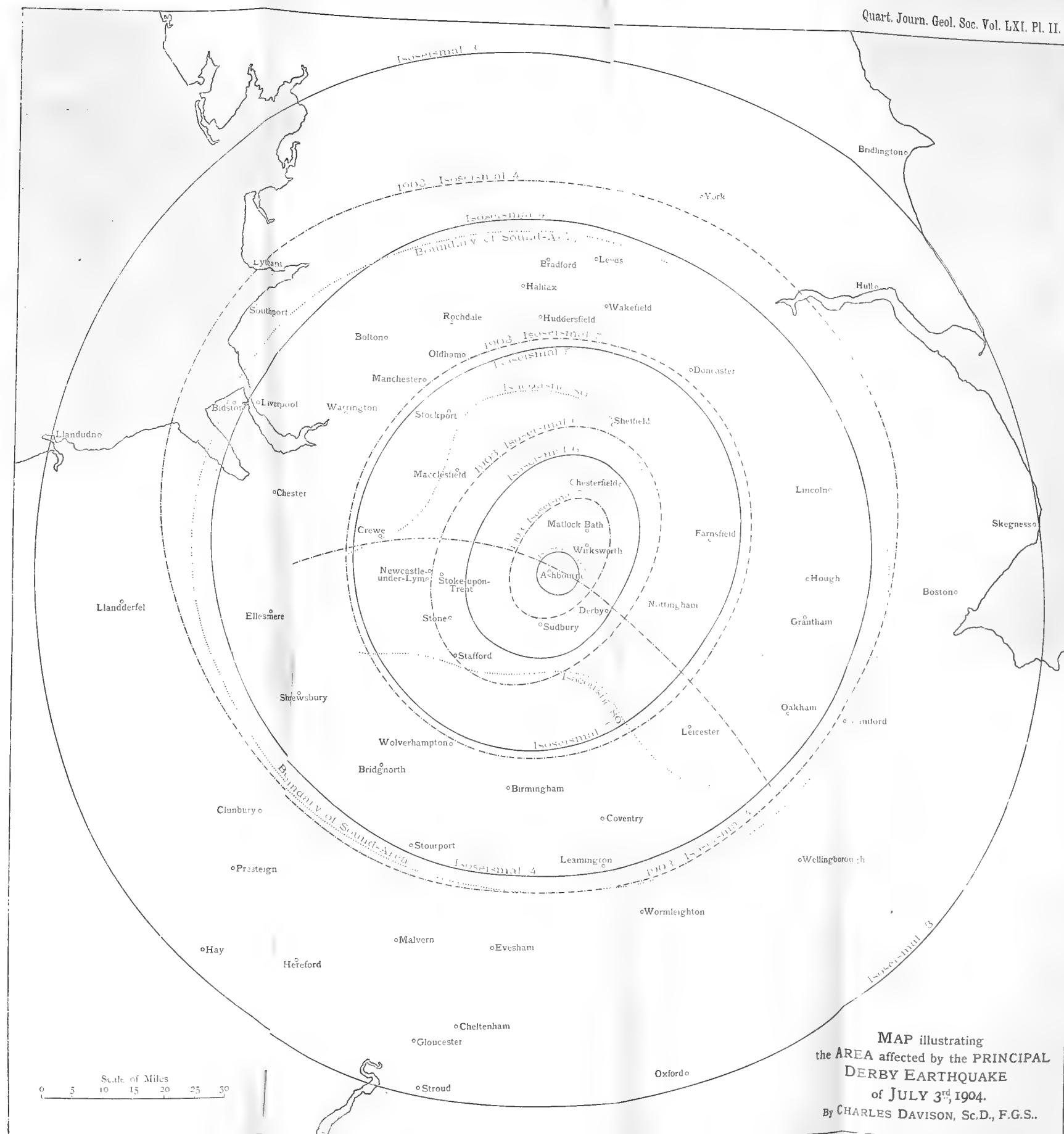
The shock is uniformly described as a continuous series of rapid vibrations, the average of four estimates of its duration being  $3\frac{1}{2}$  seconds. The sound was heard by 96 per cent. of the observers, and was compared to passing vehicles in 28 per cent. of the records, to thunder in 39 per cent., to wind in 11, to the fall of a load of stones in 6, and to explosions in 17 per cent. The beginning of the sound either preceded or coincided with that of the shock; the end of the sound generally coincided with that of the shock.

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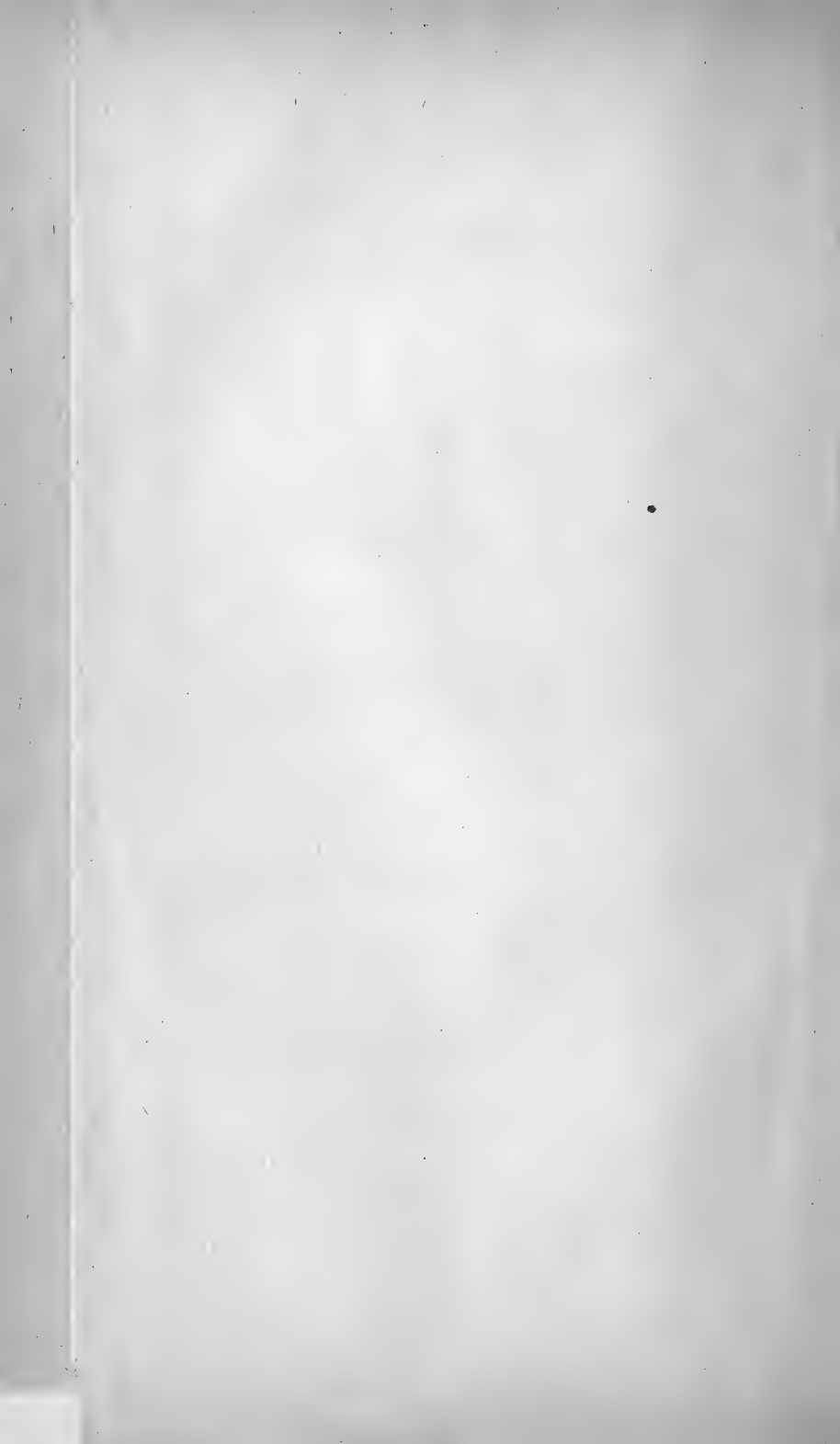








MAP illustrating  
the AREA affected by the PRINCIPAL  
DERBY EARTHQUAKE  
of JULY 3<sup>rd</sup> 1904.  
By CHARLES DAVISON, Sc.D., F.G.S..



## V. ORIGIN OF THE EARTHQUAKES.

The elements of the originating fault, as determined by the seismic evidence for both the principal earthquake and the after-shock, are as follows:—(1) the mean direction of the fault is from N.  $31^{\circ}$  E. to S.  $31^{\circ}$  W.; (2) its hade is to the north-west; and (3) the fault must pass through a point a short distance to the south-east of the centre of the isoseismal 7, that is, it must pass through or near the village of Hognaston. Comparing these elements with those obtained for the fault in action in 1903, we see that they are almost identical, the only difference being the slight one of 2 degrees in the mean direction of the fault. We may, therefore, conclude with some probability that the two earthquakes originated in slips along the same fault; and the probability seems strengthened when we consider that the two epicentres in both earthquakes were practically coincident.

In 1903 there was no distinct preparation for the earthquake of March 24th; the impulses occurred simultaneously within the two foci and were very nearly equal in strength, and there was no sensible movement in the interfocal region of the fault. In less than 4 hours two small slips took place in unknown parts of the fault; and 40 days later, on May 3rd, the increased stresses at both ends of the interfocal region resulted in a slip chiefly within that region, partly perhaps within the nearer lateral margins of the foci, but closer to the surface than the two principal slips of March 24th.

In 1904, on the other hand, there was a preliminary slip within the north-eastern or Wirksworth focus, followed in less than an hour by the principal slips in both foci, that within the south-western or Ashbourne focus being the more pronounced and succeeding the other by about a second or even less. In this case the foci were not completely detached, for throughout the interfocal region there was a slight displacement, comparable in magnitude with that which occurred in the marginal regions of the principal foci. In other words, the nearer margins of these foci coalesced. About 8 hours later the increased stresses resulting from these movements precipitated an interfocal slip, at about the same depth as the previous slips in the principal foci. With this, the series of movements seems to have terminated, unless there were two small creeps a few hours later within the Wirksworth focus.

## EXPLANATION OF PLATE II.

Map of the area affected by the principal Derby earthquake of July 3rd, 1904, on the scale of 15 miles to the inch.

[For the Discussion, see p. 33.]

3. TWIN-EARTHQUAKES. By CHARLES DAVISON, Sc.D., F.G.S.  
(Read December 21st, 1904.)

I. INTRODUCTION.

THE essential characteristic of a twin-earthquake is the existence in the shock of two maxima of intensity connected by weaker tremulous motion, or the division of the shock into two parts separated by a brief interval of rest and quiet. This feature, however, is not entirely peculiar to twin-earthquakes; for, occasionally, one earthquake is succeeded by another so rapidly as to simulate a twin-earthquake in this respect. A closer investigation of the phenomena shows, as will be seen, that the two parts or maxima of a twin-earthquake originate in two detached, or practically-detached, foci; whereas, in a double earthquake, the foci are either coincident or overlapping. A further distinction, partly dependent on the former, may be noted. In all parts of the disturbed area the member of a double earthquake which occurs first is felt first. In a twin-earthquake, on the other hand, the second impulse may, but does not necessarily, occur before the vibrations from the first focus have reached the other; so that, over most of the disturbed area, the vibrations first felt are those which come from the nearer focus, whether that focus was first in action or not. In a double earthquake the second shock is a consequence of the first; in a twin-earthquake each is independent of the other. In other words, a double earthquake is the result of successive impulses; a twin-earthquake is due to a single generative effort.

As examples of twin-earthquakes, may be mentioned the Colchester earthquake of April 22nd, 1884; the Cornwall earthquake of May 17th, 1892; the Pembroke earthquakes of August 18th, 1892, and November 2nd, 1893; the Leicester earthquake of August 4th, 1893; the Hereford earthquake of December 17th, 1896; the Carlisle earthquake of July 9th, 1901; and the Derby earthquakes of March 24th, 1903, and July 3rd, 1904. Also, among the shocks of other lands, the Neapolitan earthquake of 1857, the Andalusian earthquake of 1884, the Charleston earthquake of 1886, the Rivieran earthquake of 1887, and the Calabro-Messinese earthquake of 1894. The Cornish earthquakes of March 29th and April 1st, 1898, are typical examples of double earthquakes.<sup>1</sup> It is also possible that a few earthquakes may belong to both classes. The Leicester earthquake of June 21st, 1904, was probably a twin, so far as regards the shocks at 3.30 and 5.28 A.M., while the latter shock was itself a double earthquake.

During the last 16 years (1889-1904) the total number of earthquakes recorded in Great Britain is 160. Of these, eight, or 1 in 20, were twins. They include five out of the seven

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 1-7.

shocks which, during that time, disturbed areas of more than 10,000 square miles; while the four strongest shocks of the last 21 years were all twin-earthquakes. Earthquakes of the first magnitude, however, such as the Japanese earthquake of 1891 or the Indian earthquake of 1897, are far more complex than twin-earthquakes, both in their nature and origin.

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## III. NATURE OF TWIN-EARTHQUAKES.

### Wide Area of Observation.

The wide area over which the twin-shock is felt is perhaps the strongest evidence that the phenomenon is not of local origin. In the Hereford earthquake of 1896, the places where it was felt are distributed almost uniformly over the whole district bounded by the isoseismal 5, or over more than 40,000 square miles. Towards the north-west it was also perceptible in Westmorland, in the Isle of Man, and in Ireland, or very nearly to the boundary of the disturbed area. The twin-shock of the Pembroke earthquake of 1892 was also observed almost to the limits of the disturbed area, from Rhyl to the Scilly Isles, and from Worcester to Tullow in County Carlow. In the Pembroke earthquake of 1893 it was again noticed in nearly all parts of the disturbed area, and at places so near its boundary as Derby, Ashley, and Bournemouth. The twin-shock of the Derby earthquake of 1903 was recorded

by 68 per cent. of the observers, and was perceptible over the whole disturbed area of about 12,000 square miles. That of the following year was felt over an area of about 8000 square miles, or nearly one-third of the disturbed area. In the Andalusian earthquake of 1884 both parts of the shock were felt as far as Madrid, which is 170 miles from the epicentre. In the Rivieran earthquake of 1887 they were observed at many towns and villages in the central zones, and even as far as Salò and Vicenza, which are distant respectively 177 and 210 miles from the epicentre; but the weaker part was imperceptible in Switzerland and in other regions near the boundary of the disturbed area. The twin-shock of the Charleston earthquake of 1886 was felt at several places more than 600 miles away from the epicentre.

### Relative Nature of the two Parts.

As a general rule, the observations under this heading refer to the relative intensity of the two parts of the shock. In the Pembroke earthquake of 1892 the parts differed little in intensity; but, over all the land-area disturbed, the second seems to have been slightly stronger than the first. In that of 1893, the second series was the stronger near the western end of the isoseismal 6 and farther west in Pembrokeshire, and the first in other parts of the area. For the Hereford earthquake of 1896 the observations are more detailed. These show that, in the north-western half of the disturbed area, the first part of the shock was the stronger, of greater duration, and consisted of vibrations of longer period; that, in the south-eastern half, the same features characterized the second part of the shock; and, moreover, that the boundary-line between these two portions of the disturbed area was not straight, but concave towards the south-east. In the Derby earthquake of 1903, the two parts were so nearly equal in intensity that observers in the same place differed greatly in their estimates. All over the disturbed area, however, 61 per cent. of the observers state that the first part was the stronger, and 39 per cent. the second; and this proportion was nearly the same on both sides of the minor axes of the isoseismal lines. The first part of the Derby earthquake of 1904 was also generally regarded as the stronger, but the difference in intensity between the two parts was clearly greater in the south-western than in the north-eastern half of the disturbed area. In the Charleston earthquake of 1886 the two parts were of nearly-equal intensity, but at most places the first is described as the stronger; in the Rivieran earthquake of 1887, the second part of the shock was the stronger all over the disturbed area, except within a small area near Nice; and in the Calabro-Messinese earthquake of 1894 the second part seems to have been everywhere stronger than the first. Thus, not only does the order of relative intensity vary in different earthquakes, but in the same earthquake there may exist regions in which the order of intensity is reversed.

### Mean Duration of the Interval between the two Parts.

In British earthquakes the duration of the interval between the two parts rarely exceeds a few seconds in length. Taking, first, the whole disturbed area, the mean duration of the interval was 2.1 seconds in the Derby earthquake of 1904; 2.3 seconds in the Pembroke earthquake of 1893; 2.5 seconds in the Leicester earthquake of 1893; 3 seconds in the Pembroke earthquake of 1892, the Carlisle earthquake of 1901, and the Derby earthquake of 1903; and 3.6 seconds in the Hereford earthquake of 1896. For the earthquakes of other countries estimates are somewhat rare; but the interval was only a few seconds in length in the Neapolitan, Andalusian, and Rivieran earthquakes. In the Calabro-Messinese earthquake of 1894 five estimates, varying from 1 to 3 seconds, give an average of 2.1 seconds. The Charleston earthquake forms an exception from this point of view; for the two maxima were separated by about 34 seconds at Charleston, and the mean duration of the interval throughout the disturbed area was slightly less than half a minute.

Again, the mean duration of the interval varies but little at different distances from the epicentre. In the central district of the Hereford earthquake of 1896 it was 3.4 seconds, in the surrounding zone 3.3 seconds, and in the outermost zone only 4.1 seconds. In the Derby earthquake of 1903, the mean duration was 2.9 seconds within the isoseismal 6, 3.0 seconds between the isoseismals 6 and 5, and 3.0 seconds beyond the latter isoseismal. In the Derby earthquake of 1904 the averages for the corresponding zones were 2.2, 2.0, and 2.1 seconds. In the Neapolitan earthquake, the duration was 1 or 2 seconds at Potenza, and a few seconds at Naples; in the Andalusian earthquake, 1 or 2 seconds close to the epicentre and in the surrounding zone, and 3 or 4 seconds at Madrid, distant 170 miles. The slight increase with the distance in some cases is no more than might be due to the gradual extinction of the weak vibrations at the end of the first series and beginning of the second; and it is therefore probable that the mean interval between the maxima of intensity is practically constant at all distances from the centre.

### Coalescence of the two Parts.

While, in most cases, the twin-shock is perceptible over the greater part of the disturbed area, there may exist within it a narrow band along which the two parts are no longer distinctly separated, but coalesce and form a single continuous series of vibrations. As the two movements are felt together in this band, I propose to call it the synkinetic band, and the median line of the band the synkinetic line. Such a band probably exists in most, perhaps nearly all, British twin-earthquakes, but in only three cases can it be definitely traced—in the Hereford earthquake

of 1896, and in the Derby earthquakes of 1903 and 1904. The band is only a few miles in width, and crosses the central curves at right angles to their longer axes. In the Derby earthquake of 1903 the synkinetic band was straight, and in the other two earthquakes curved, the concavity in the case of the Hereford earthquake facing south-eastward, and in that of the Derby earthquake of 1904 south-westward. In every case, it is worthy of notice that two maxima of intensity, connected by weaker tremulous motion, were distinguished by careful observers close to the boundaries of the synkinetic band.

### Sound-Phenomena.

As a rule, though not invariably, the sound is heard with each part of the shock; sometimes the shock is not felt, and two sounds are alone observed. The stronger part of the shock is accompanied by the louder sound, but the two parts of the sound differ less in intensity than the two parts of the shock; also, the sound is often heard before and after the shock begins and ceases to be sensible. Thus, when the two parts of the earthquake coalesce within and near the synkinetic band, the sound receives a notable increase of strength over a comparatively-wide region; while the strongest vibrations of the two parts of the shock are of such brief duration that they coalesce only near the synkinetic line. Observations of the reinforced sound are therefore common, and those of the reinforced shock are rare: the result being that the isoseismals show little, if any, deflection near the synkinetic band; while the isacoustic lines (or lines of equal sound-intensity) are so much distorted that they cling to the synkinetic band, and share in its straightness or curvature.

### IV. TWIN-EARTHQUAKES CONNECTED WITH A TWIN-FOCUS.

In several earthquakes, the isolation of the two series of vibrations has been so marked that seismologists have felt it necessary to offer some explanation of their origin. The brevity of the interval has been tacitly assumed to preclude a repetition of the impulse within the same focus; and the two series have been generally referred to a single impulse, the separation of the earth-waves being effected by subterranean reflection or refraction, or ascribed to the existence of direct and transverse waves. Thus, in the Neapolitan earthquake of 1857, Mallet noticed the difference in direction between the two parts of the earthquake, and regarded the second part as a reflected shock, although he offered a somewhat different explanation for the outlying region of Naples. In the Colchester earthquake of 1884, Prof. Meldola & Mr. White also attribute the second part to reflection; they consider the existence of two initial disturbances as improbable, although they notice that the distribution of damage to buildings gives the impression that there were two separate foci. Profs. Taramelli & Mercalli suggest



that the two parts of the Andalusian earthquake of 1884 were respectively waves of direct and transverse vibrations, and they account for the greater intensity of the second part by supposing that the transverse vibrations were reinforced by reflected direct vibrations.

A distinct advance was made, 2 years later, when Major Dutton, relying on the distribution of damage, determined the existence of two foci in the Charleston earthquake of 1886. In the following year Prof. Mercalli, in his investigation of the Rivieran earthquake of 1887, showed that the time-records and the observations on the direction of the shock implied the existence of two submarine foci, one to the south of Oneglia and the other not far from Nice. The same seismologist, in his valuable memoir on the Calabro-Messinese earthquakes, concludes, from the form of the isoseismals and the observations on the direction, that the earthquake of 1894 also originated in a double focus. I will now give some reasons for believing that this view offers the best interpretation of the evidence so far collected.

In the first place, twin-earthquakes cannot be generally due to reflection or refraction of the earth-waves at the bounding surfaces of different rock-masses, although here and there the shock may be duplicated in this manner. The wide area over which the twin-shock is almost uniformly felt, shows that it is not a local phenomenon. The existence of a synkinetic band, the almost-constant brevity of the interval between the two parts, and the definite law of variation in their relative intensity, duration, and period of vibration, are equally opposed to a haphazard origin. Moreover, on this theory, the first part of the shock should be the stronger, for energy is lost by the reflection or refraction of a wave. And, again, of the earthquakes originating in a given district, a few are twins and the majority simple; yet, according to the explanation here considered, the earth-waves should undergo deflection at the same surfaces on every occasion.<sup>1</sup>

Nor can the two parts of a twin-earthquake be respectively waves of direct and transverse vibrations; for, if they were, there would be no synkinetic band crossing the central district, and the relative nature of the two parts would be uniform throughout the disturbed area. Also, the interval between the two series does not increase, as it should do, with the distance from the origin; at a distance of 170 miles it is only a few seconds, instead of 2 or 3 minutes, in length. The earthquake-sound accompanies both series in precisely the same manner; if the second series consisted of transverse vibrations only, it would be unattended by any sound. Both parts have been felt at sea,<sup>2</sup> and transverse vibrations cannot be propagated in a liquid. Lastly, if the second series consisted of transverse vibrations, every earthquake would be a twin-earthquake.

<sup>1</sup> A few, but by no means all, of the after-shocks of the Andalusian earthquake of 1884 were apparently twins.

<sup>2</sup> In the Rivieran earthquake of 1887, two strong shocks at a few seconds' interval were felt on board a steamboat, on its way from Genoa to Marseilles.

Further, twin-earthquakes are not due to a repetition of the impulse within the same, or an overlapping, focus; for, if so, the order of relative intensity, etc., would not vary in a definite manner throughout the disturbed area, the two parts of the shock would never coalesce, and the mean duration of the interval would not generally be confined between the limits of about 2 and 4 seconds.

Thus, as twin-earthquakes are not due to the separation of the waves arising from a single impulse, nor to repeated impulses in the same focus or in overlapping foci, it follows that they must be caused by impulses in two detached, or practically-detached, foci. On this view of their origin, the phenomena described above admit of a ready explanation:—

(1) The twin-character of the shock would be perceptible as far as the weaker of the two parts can be felt; and the fact that both parts are sometimes observed over the whole, or most, of the disturbed area, shows that the two initial impulses were of nearly-equal intensity.

(2) In the neighbourhood of the epicentre corresponding to the weaker impulse, the vibrations from that focus may be of greater intensity than those from the more distant focus. The stronger impulse does not necessarily occur first; and thus the order of relative intensity may vary in different earthquakes, and in different parts of the disturbed area of the same earthquake. I shall return to this subject in the next section.

(3) When, as seems to be generally the case, the interval between the two parts is less than the time required to traverse the distance between the two foci, the two series of vibrations must coalesce at the surface, along a band passing between the two epicentres and crossing the line that joins them approximately at right angles. From the form of the synkinetic band we can determine which focus was first in action. When the synkinetic band is straight, the two impulses must have taken place simultaneously; when the band is curved, its convexity must face the focus first in action, for the vibrations from that focus have to travel farther before they meet the vibrations from the second focus.

#### V. RELATIONS BETWEEN THE ISOSEISMAL LINES IN A TWIN-EARTHQUAKE.

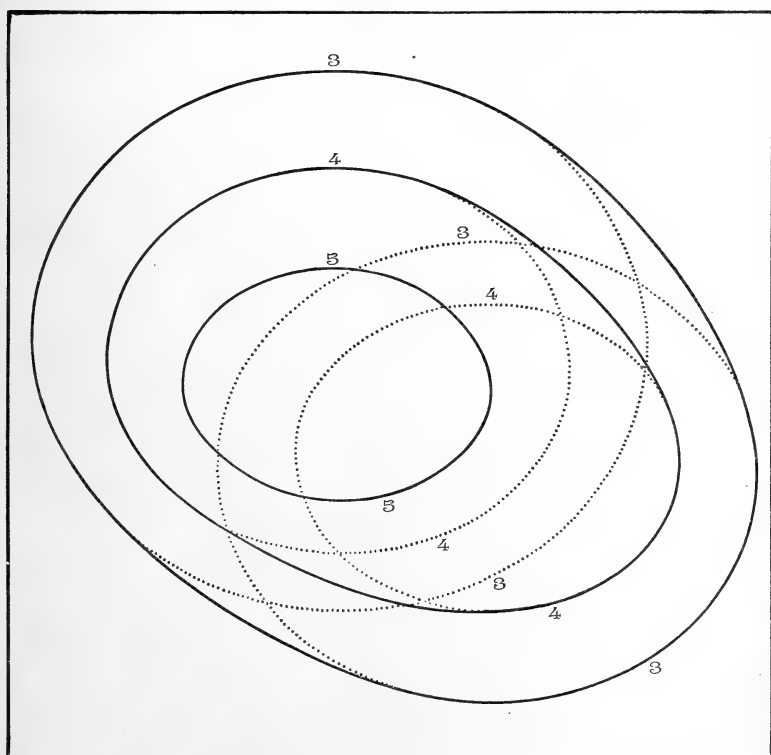
In a twin-earthquake, observations of the intensity of the shock refer, unless otherwise stated, to that of the stronger part; and thus, when the order of relative intensity varies throughout the disturbed area, the isoseismal lines so determined are a combination of the isoseismal lines corresponding to both foci. In such a case, the isoseismals often present certain features which are characteristic of their origin.

##### Excentricity of the Resultant Isoseismal Lines.

In a simple earthquake the isoseismal lines are roughly elliptical in form, their longer axes are parallel, or nearly so, to the strike of

the originating fault; and, in the neighbourhood of the epicentre, the distances between successive isoseismal lines are greater on the side towards which the fault fades than on the other side. In fig. 1 (below) the isoseismal lines corresponding to two foci are represented by dotted curves, and the impulses are supposed to differ in intensity, so that while, for the western focus, three isoseismal lines (of

Fig. 1.—*Excentricity of isoseismals in twin-earthquakes.*



intensities 5, 4, and 3) can be drawn, for the eastern focus there are only two isoseismal lines (of intensities 4 and 3). The resultant isoseismal lines would be drawn in the form represented by the continuous curves. Thus, when the two impulses differ in intensity, as in the Leicester earthquake of 1893, the Hereford earthquake of 1896, the Carlisle earthquake of 1901, or the Derby earthquake of 1904, the most marked characteristic of the resultant isoseismal lines is the excentricity of the inner curve with respect to the others.

### Divergence of the Isoseismal Axes.

The curves in fig. 1 (p. 25) illustrate another peculiarity of the resultant isoseismal lines. If the fault hades in the same direction in both foci, the axes of the resultant isoseismals will be approximately parallel. If, as assumed in the figure, the fault hades to the north in the western focus and to the south in the eastern focus, the isoseismals of the western focus will be farther apart on the north side than on the south, while those of the eastern focus will be farther apart on the south side than on the north. The axis of the isoseismal 5 will therefore be directed eastward and westward, and those of the resultant isoseismals 4 and 3 will run from a few degrees north of west to a few degrees south of east. An example of this divergence of the isoseismal axes will be seen in the Leicester earthquake of 1893, in which the axis of the isoseismal 5 runs from W.  $30^{\circ}$  N. to E.  $30^{\circ}$  S., while those of the resultant isoseismals 4 and 3 are, respectively, from W.  $40^{\circ}$  N. to E.  $40^{\circ}$  S. and north-west to south-east.

### Areas of Opposite Relative Intensity.

If the vibrations which proceed from the two foci differ initially in their intensity, duration, and period, the disturbed area may be divided into regions in which the order of relative intensity, etc., varies. In the case of the period of vibration, and roughly also in that of duration, the synkinetic line separates one such region from the other. The variation of relative intensity is, however, more complicated, as the intensity of either part depends on the distance from the corresponding focus.

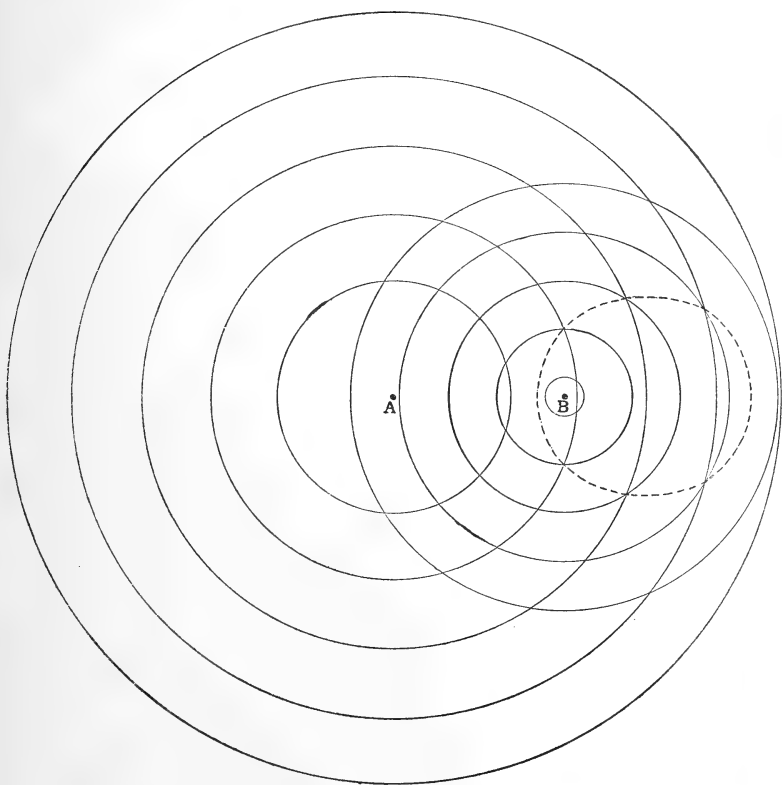
In fig. 2 (p. 27) the points A & B indicate the two epicentres, A corresponding to the focus in which the initial impulse was the stronger. The isoseismal lines for each focus are represented, for simplicity's sake, by circles. At the points where similar isoseismals intersect, both parts of the shock are of the same intensity. The broken line passing through these points thus separates the disturbed area into two districts, within the smaller of which the vibrations from the weaker focus are stronger than those from the other. It is evident that the centre of this area does not coincide with the epicentre B, but is displaced on the side away from A; and that its boundary is practically an unclosed curve when the initial impulses are of nearly-equal intensity.

The order of relative intensity at any point of the disturbed area depends on the order in which the impulses occur in the two foci, and on the length of the interval that elapses between their occurrence. Figs. 3-6 (p. 28) illustrate the different cases that may arise. In each of these, the western focus is supposed to be that in which the stronger impulse takes place, while the small circle bounds the area within which the vibrations from the eastern focus were felt more

strongly at the surface. The districts in which the first part of the shock was the stronger are shaded by horizontal lines, and those in which the second part was the stronger by vertical lines.

If the interval between the impulses be greater than the time taken by the earth-waves to travel from one focus to the other, and

Fig. 2.—*Variation of relative intensity in twin-earthquakes.*



the western focus be first in action, the distribution of relative intensity will be that represented in fig. 3. If the eastern focus be first in action, the order of relative intensity will simply be reversed.

On the other hand, if the interval between the impulses be less than the time of transit from one focus to the other, a synkinetic band will cross the disturbed area between the two epicentres. In figs. 4-6 the synkinetic line is indicated by the hyperbolic curve. In fig. 4 the western focus, and in fig. 5 the eastern focus, is supposed to be first in action. Fig. 6 represents a modification of

fig. 4, in which the synkinetic line intersects the area within which the vibrations from the eastern focus are felt more strongly. It is evident that there is no corresponding modification of fig. 5, for the

*Figs. 3-6, illustrating different cases of relative intensity in twin-earthquakes.*

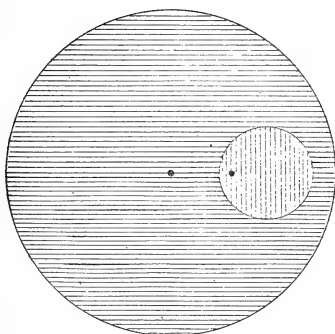


Fig. 3.

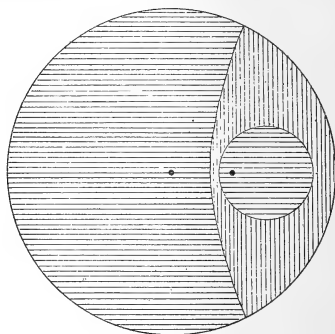


Fig. 4.

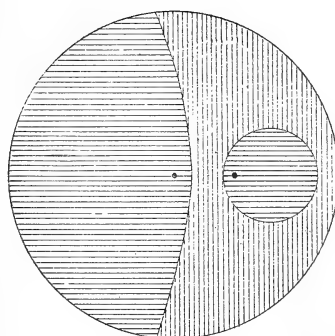


Fig. 5.

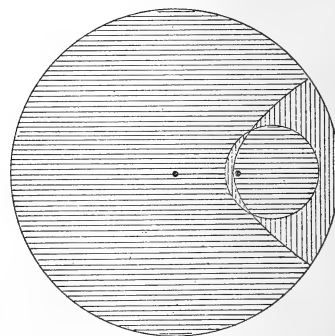


Fig. 6.

boundary of the latter area is always nearer to the eastern than to the western epicentre, while the synkinetic line is always nearer the epicentre of the focus last in action.

## VI. ELEMENTS OF THE TWIN-FOCI.

### Distance between the Twin-Epicentres.

The exact determination of the positions of the twin-epicentres is a problem of some difficulty, and it is only in one or two cases that it has been approximately solved. Major Dutton, in his

valuable memoir on the Charleston earthquake, publishes two maps of the isoseismal lines which traverse the meizoseismal area, one representing the impressions of Mr. Earle Sloan, who surveyed the district with great care, the other giving his own interpretation of the same evidence. In neither case do the isoseismal lines correspond to the degrees of any definite scale of seismic intensity; but, although differing widely in detail, they agree in their expansion around two small districts which probably represent the epicentres corresponding to the twin-foci. In the Neapolitan earthquake, the distribution of the seismic death-rate gives a fair approximation to the positions of the epicentres. The south-eastern epicentre must be close to Montemurro and Saponaro, where the death-rates were respectively 71 and 50 per cent.; while the north-western epicentre must be near Polla, where the death-rate was about 30 per cent., Polla being 4 miles from the single epicentre ascertained by Mallet from observations on the direction of the shock.

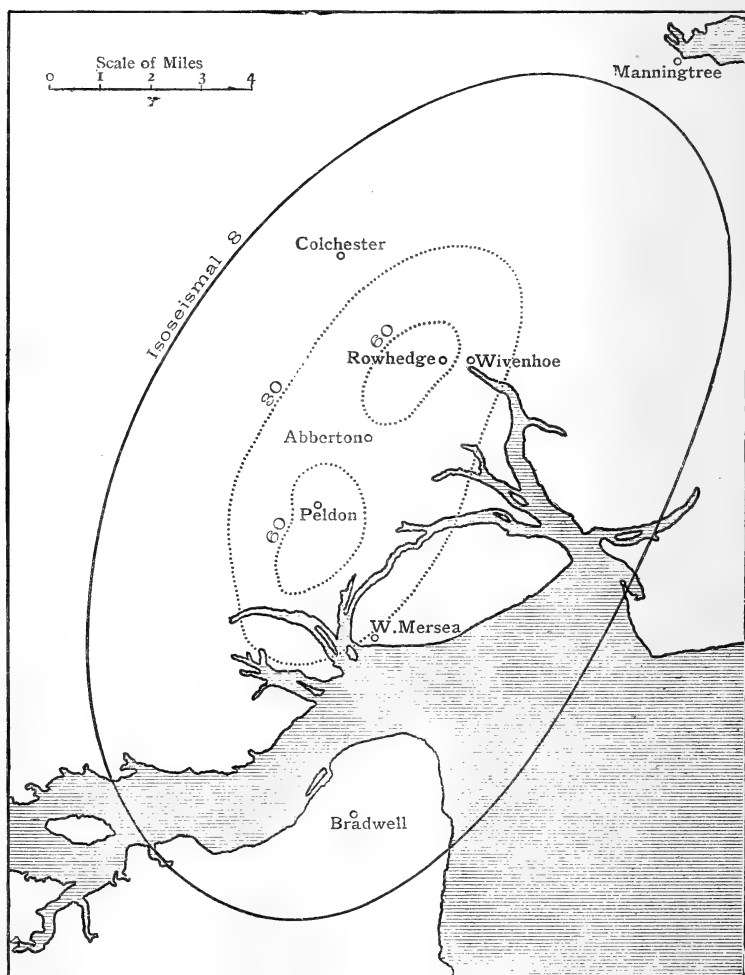
More satisfactory materials for the purpose are provided by the Colchester earthquake of 1884. In their well-known report, Prof. Meldola & Mr. White note the existence of two areas of maximum destruction, one near Peldon and Abberton, the other near Wivenhoe and Rowhedge. They also give a table of the places where damage occurred, with the population of each in 1881 and the number of buildings repaired. Assuming that there are five persons on an average in every house, the percentage of houses needing repair may be calculated for each place, and from these may be drawn curves of equal percentages of such houses. In fig. 7 (p. 30) the continuous line represents the isoseismal 8, while the dotted lines are the curves corresponding to percentages of 60 and 30 respectively. As the Colchester earthquake is known from other evidence to have been a twin-earthquake, it is probable that the epicentres are closely surrounded, if not outlined, by the two inner curves of percentage 60.

If the innermost isoseismal is excentric, the epicentre corresponding to the stronger impulse must be situated close to its centre, while the other epicentre probably occupies a similar position with regard to the centre of the next isoseismal, though perhaps slightly farther removed from it. In this way are determined approximately the positions of the epicentres of the Leicester and Pembroke earthquakes of 1893, the Hereford earthquake of 1896, the Carlisle earthquake of 1901, and the Derby earthquake of 1904. In the Pembroke earthquake of 1892, the epicentre corresponding to the weaker impulse was probably submarine; while, for the Derby earthquake of 1903, we have to rely upon the form of the inner isoseismals.

The following estimates of the distance between the twin-epicentres are therefore only approximate; those for British earthquakes may err by as much as a mile, the others by even more. The highest estimate is that of about 35 miles for the Rivieran earthquake of 1887; but, in this case, there is some uncertainty as to the position of the secondary epicentre near Nice. In the

Neapolitan earthquake of 1857 the distance is 24 miles; in the Charleston earthquake of 1886, 13 miles. Turning to British earthquakes, the distance is 23 miles in the Carlisle earthquake of 1901;

Fig. 7.—*Map illustrating the areas of maximum intensity of the Colchester earthquake of 1884.*



17 miles in the Leicester earthquake of 1893; 8 or more miles in the Pembroke earthquake of 1893; 8 or 9 miles in the Hereford earthquake of 1896 and the Derby earthquake of 1903; 6 or 7 miles in the Derby earthquake of 1904; and 4 miles in the



Colchester earthquake of 1884. If we may regard the two Leicester earthquakes of 1904 as members of a twin-earthquake, the distance would be about 12 miles; and it is by no means impossible that the Inverness earthquake of 1901 was a twin-earthquake, in which the foci were so close as to give the impression of a double earthquake with overlapping foci. Excluding the two last earthquakes, the average distance between the epicentres of recent twin-earthquakes in this country is 10 or 11 miles.

### Form of the Twin-Foci.

As a rule, the foci are elongated approximately in the direction of the line joining them. In the Charleston earthquake, the epicentral isoseismals in Mr. Earle Sloan's map are elongated in the neighbourhood of both epicentres. Two of the strongest after-shocks of the Rivieran earthquake were connected, according to Prof. Mercalli, one with the Oneglia focus and the other with the Nice focus; and the longer axes of the disturbed areas of both are roughly parallel to the line joining the foci. In the Leicester earthquake of 1893 and the Hereford earthquake of 1896, the axes of the excentric isoseismals are nearly parallel to those of the isoseismals which surround them. The Hereford earthquake of 1896, the Carlisle earthquake of 1901, the Derby earthquakes of 1903 and 1904, and probably also the Pembroke earthquake of 1893, were either preceded or followed by shocks which originated in the interfocal region of the fault and disturbed areas elongated in the same directions as the inner isoseismals of the principal earthquakes. It is difficult, therefore, to resist the conclusion that the two foci are portions of one and the same fault.

### Relative Depth of the Twin-Foci.

Though estimates of the absolute depth of the seismic focus are in every case subject to considerable error, there is some reason for thinking that the two foci of a twin-earthquake may be situated at different depths. Major Dutton estimates the depth of the Woodstock focus of the Charleston earthquake at about 12 miles, and that of the Rantowles focus at about 8 miles. Prof. Mercalli believes that the Oneglia focus of the Rivieran earthquake lay at a depth of about  $10\frac{3}{4}$  miles; while, from the rapid decay of the vertical component of the motion, he infers that the Nice focus was nearer to the surface. In both these cases the weaker impulse seems to have been connected with the shallower focus. The British earthquakes, in which the innermost isoseismal is excentric, apparently lead to a different conclusion. The surrounding isoseismals are not oval in form, and wider in the neighbourhood of the excentric isoseismal than elsewhere, but nearly or quite elliptical. This implies that the intensity of the weaker part of the shock diminished more slowly outwards from the epicentre than

that of the stronger part; in other words, that the weaker part of the shock was connected with the deeper focus.

### Hade of the Fault within the Twin-Foci.

On this point we have little knowledge. In the Leicester earthquake of 1893, the fault hades to the north-east within the north-western focus, and in the opposite direction in the south-eastern focus. In the Hereford earthquake of 1896, the hade within the north-western focus is to the north-east, and within the south-eastern focus probably in the opposite direction. There is, however, no evidence of any such change of hade in the Carlisle earthquake of 1901, or in either of the Derby earthquakes of 1903 and 1904.

## VII. ORIGIN OF TWIN-EARTHQUAKES.

In a simple earthquake, the immediate consequence of the parent fault-slip is a change of stress within and near the focus, especially an increase of stress along its margins. The after-slips consequently take place, either in the focal region or just beyond it. Thus, the foci of successive earthquakes are not detached, but are either coincident or overlapping.

A twin-earthquake is clearly of a different and more complex origin. Through a single effort, movements occur almost simultaneously in two distinct regions of the fault; and these regions are probably situated at different depths, and are separated by a portion of the fault in which there is little or no sensible displacement. Such a movement could hardly be due to an interrupted slip; for this would involve an interval of time between the component slips long enough for the increased stress resulting from the first slip to take effect in the second focus, and therefore longer than the time of transit between the two foci.<sup>1</sup> It would, however, be caused by the growth of a fold cut transversely by the originating fault; a growth that would render the anticline of the fold more anticlinal and the syncline more synclinal, while the middle limb would remain practically undisturbed. The seismic focus would thus consist of two detached portions situated at different depths.

Now, in recent British twin-earthquakes, the distance between the epicentres ranges from 4 to 23 miles, and, on an average, is about 10 or 11 miles. If, then, the above explanation be the correct one, this average should not differ much from the mean distance between successive anticlines and synclines. No series of measurements have, I believe, been made of this distance for British crust-folds; but a rough estimate can be obtained from Prof. Marcel Bertrand's map of the synclinal folds of France. Along several different lines, varying in length from 127 to 442 miles, the average distance between successive synclines lies between 18 and 24 miles, or the average distance between successive anticlines

<sup>1</sup> The Charleston earthquake may have originated in this manner.

and synclines between 9 and 12 miles. The correspondence with the average distance between twin-epicentres is thus close enough to support or confirm the explanation given.

A step in the growth of a crust-fold, such as that contemplated, would leave the middle limb subjected at both ends to increased stresses, which should, after a short interval, be relieved by a slip occupying the whole of the interfocal region, and possibly intruding on the areas of the twin-foci.<sup>1</sup> As these interfocal slips are simple in character—the shock showing no signs of duplication—it is probable that the movement of the middle limb is one of translation and not, as in the principal displacement, of rotation: as if the growth of the arches were followed by a much smaller bodily advance of the crust-fold.

On the view here given, it follows that simple and twin-earthquakes differ essentially in their origin. A simple earthquake is caused by movements connected with a single system of folding. The Caernarvon earthquake of 1903, for instance, was produced by a fault-slip belonging to the Caledonian system, the Somerset earthquakes of 1893 and the Exmoor earthquake of 1894 by fault-slips of the Charnian system. On the other hand, the parent-faults of the Leicester earthquake of 1893 and the Hereford earthquake of 1896 belong to the Charnian system, while the earthquakes themselves were due to the growth of Caledonian folds; and, in like manner, the Colchester earthquake of 1884 and the Derby earthquakes of 1903 and 1904 were connected with the growth of Charnian folds, the slips taking place along faults belonging to the Caledonian system. Most of the earthquakes felt in this country are thus merely incidents in the growth of faults; and it is surely not without significance that the strongest of all should be mainly due to the continued formation of some of our most important crust-folds.

#### DISCUSSION ON THE FOREGOING THREE PAPERS.

Prof. WATTS, referring to the paper on the Leicester earthquakes, drew attention to the map of Charnwood Forest which he exhibited, and described the general run of the faults observed by himself. The normal faults and thrusts on the north-east side of the anticline probably hade to the north-east, while those on the opposite side seem to hade south-westward. But the anticlinal fault which the Author had selected as being the one that probably gave rise to the two Leicester earthquakes might hade either way, and might even hade north-eastward in part of its course and south-westward elsewhere. He further referred to the conversation which he had had with Prof. Lapworth on the third paper, who had pointed out to him how twin-earthquakes occurring along the lines of Charnian

<sup>1</sup> In the Carlisle earthquake of 1901 the interfocal slip occurred after a lapse of 22 minutes; in the Derby earthquake of 1903 after 40 days, in that of 1904 after less than 8 hours; and, probably, in the Pembroke earthquake of 1893 after 16 minutes.

faults were almost certainly due to Caledonian movement acting from north-west to south-east. Charnian movement along the same lines would be more likely to produce single earthquakes. In conclusion, he read the following extract from a letter which he had received from the AUTHOR:—

‘Having spent the greater part of my leisure-time during the last sixteen years in the study of recent British earthquakes, I propose now to continue my enquiry backward, so as to include all known earthquakes in this country, my objects being to determine as far as possible the distribution of seismic activity in space and time, and to investigate the laws according to which faults grow.

‘I am aware that to recover more than the scantiest data regarding long-past earthquakes is now an almost-impossible task, but an attempt to collect and preserve what is already known seems to me worth making. If any Fellow of the Geological Society should be able and willing to aid me in this work, to however small an extent, or induce others to do so, I need not say how welcome such help would be.

‘The most useful notes would be those relating to earthquakes before the year 1891, and especially to the Hereford earthquakes of October 6th, 1863, and October 30th, 1868; the earthquakes felt in the North of England on March 15th, 1869, and March 17th, 1871, and in the North-West of Scotland on November 28th, 1880; the Colchester earthquake of April 22nd, 1884; and the Inverness earthquakes of February 2nd, 1888, and November 15th, 1890.’

4. *On the Occurrence of ELEPHAS MERIDIONALIS at DEWLISH (DORSET). SECOND COMMUNICATION: HUMAN AGENCY SUGGESTED.* By the Rev. OSMOND FISHER, M.A., F.G.S. (Read November 9th, 1904.)

[PLATES III & IV.]

IN June 1888 I read a paper before the Society on the occurrence of *Elephas meridionalis* at Dewlish in Dorset.<sup>1</sup> Subsequent excavations were made by the late Mr. J. C. Mansel-Pleydell, of which he gave accounts in two articles in the Proceedings of the Dorset Natural History & Antiquarian Field-Club, vol. x (1889) pp. 12 *et seqq.* & vol. xiv (1893) pp. 139–41, the second of these being illustrated by photographs of the deposit. Mr. Clement Reid also, in the latter part of 1888, spent four days in investigating the locality, and described it in the Geological Survey Memoir on the geology of the country around Dorchester, 1899. This memoir contains a drawing (p. 35) copied from one of Mr. Pleydell's photographs. The photographs themselves are now reproduced (Pls. III & IV). It is not necessary to describe the locality afresh, as that has been done already by Mr. Pleydell and by myself, and subsequently very clearly by Mr. Reid. The distant fence shown in Pl. III is on the brow of the hill, and the early finds were made just beyond it. The deposit was then opened on the opposite side of it, where the pelvic bone lies, the fence being left intact. The trench was afterwards followed for about 103 feet, until it suddenly terminated in a smooth 'apse-like' end.<sup>2</sup> The photograph showing the pelvic bone (Pl. III) was taken from the farther end, looking about due north-west towards the brow of the hill. Both the views seem to show a quantity of straw lying about, which, with the hurdles, had probably been used to protect the bones.

The site in which the elephant-remains were found has some very remarkable features. It was a deep and narrow trench, with nearly-vertical sides of undisturbed Chalk. Mr. Reid says:

'The fissure (or rather trough) ended abruptly [Pl. IV], without any trace of a continuing joint; it was not a fault, for the lines of flint-nodules corresponded on each side. As deep as the excavation was carried it was still in dust-like sand.'<sup>3</sup>

This description agrees with what I saw at my last visit in September 1889. The pelvic bone shown in the photograph (Pl. III) was then lying where it is represented.

When the trench was dug out by Mr. Mansel-Pleydell, it does not appear to have been bottomed, the examination having been carried down to about 10 feet. But in my memorandum of 1887, when I investigated the section on the hillside, I noted that the

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xliv (1888) pp. 818–23.

<sup>2</sup> *Teste* Mr. Reid.

<sup>3</sup> 'Geology of the Country around Dorchester' Mem. Geol. Surv. (1899) p. 34.

base of the deposit was a smooth surface of Chalk, and Mr. Reid found it to be about 12 feet deep at this spot.

It seems impossible to account, by any natural agency, for such a trench as this on a Chalk-plateau. A stream in such a locality would be unlikely to excavate a deep and narrow channel, much less, if it did so, would it come to an abrupt ending. And, even if we could account for the natural formation of such a trench, how came it that the remains of so many elephants were found in it, and (so far as appears) of no other animals?

I have seen in a popular magazine a photograph of a trench, dug and covered with boughs, intended for the capture of elephants; and this has led me to think that the trench at Dewlish may have been made by primitive men for the same purpose. Unfortunately I cannot recover the reference to this article. Sir Samuel Baker describes this method of taking elephants by natives of Africa.<sup>1</sup> He says that an elephant cannot cross a ditch with hard perpendicular sides, which will not crumble nor yield to pressure. Pitfalls 12 to 14 feet deep are dug in the animals' routes towards drinking-places, and covered with boughs and grass. The pits are made of different shapes, according to the individual opinions of the trappers. When caught, the animals are attacked with spears while in their helpless position, until they at last succumb through loss of blood. Their flesh is eaten. The way in which they are cut up, and the flesh dried in strips, is illustrated in Mr. A. H. Neumann's 'Elephant-Hunting in East Equatorial Africa' 1898 (pp. 108 & 178). Probably in primitive times their flesh, and not their ivory, was the object for which they were killed.<sup>2</sup> If the stream which now runs at the bottom of the hill, despite subsequent changes in the contour of the country, already existed, then this trench would have been made in a position suitable to intercept the route to a drinking-place.

There seems to have been hitherto no conclusive evidence that man was contemporary with *Elephas meridionalis* in this country. Mr. W. J. Lewis Abbott has found what he believes to be worked flints in the Forest-Bed of Cromer, and he has kindly permitted me to examine them. They have also been found by Mr. O. A. Shrubsole and by others. They have certainly been flaked, but whether artificially or not, it is difficult to determine. In the 'Globe' newspaper, however, of August 16th, 1895, reference was made to the discovery, by Prof. Marcellin Boule, at Tilloux (in the Charente), of a large number of fossil remains of elephant, rhinoceros, bison, and hippopotamus, together with flint-implements and utensils.<sup>3</sup>

The diagram in my paper of 1888 (p. 819), having been drawn before the deposit had been further examined, is incorrect, for it

<sup>1</sup> 'Wild Beasts & their Ways' vol. i (1890) pp. 95 & 98.

<sup>2</sup> See, however, W. J. Lewis Abbott, Proc. Geol. Assoc. vol. xi (1891) p. 479, although this relates to *E. primigenius*.

<sup>3</sup> See also 'L'Anthropologie' vol. vi (1895) pp. 497-509. Prof. Boule now thinks that the elephant of Tilloux is *Elephas antiquus*, not *meridionalis* (as stated in the 'Globe'), and expressed himself to that effect at the International Anthropological Congress, held at Paris in 1900.

represents the deposit as clinging to the face of the hill, whereas in fact the steep scarp cuts diagonally across the trench, and the remains of elephants were abundant at that spot, where the early finds were made.

It is very remarkable that the surface of the ground here appears not to have been appreciably lowered by denudation since the Pliocene Period, unless *Elephas meridionalis* lived on much later in this neighbourhood. The trench is on a watershed, which may possibly help to account for this fact. The position of the trench, cut across diagonally by the scarp of the hill, is peculiar. It seems possible that, if the trench was artificial, this may have been intentional, because it would permit the dug-out stuff to be taken to the open end, and tipped down the hill, and so obviate the necessity of throwing it up along the sides of the pitfall. The diagonal position would also have been suitable, because, if it had been cut perpendicular to the brow of the hill, it would not have intercepted the animals going to their drinking-place; while if it had been parallel to the scarp, it would not have enabled the earth to have been conveniently taken out.

The 'dust-like' sand is perhaps blown sand. Chalk-plateaux in the neighbourhood are, in some places, covered with a sand which is probably of the age of the London Clay. The large amount of flint-gravel may be a subsequent drift from the plateau-gravel, which occupies considerable areas in the district. In fact, there are many problems yet to be solved in connection with the trench at Dewlish: but my object is to suggest that we have here the earliest record yet discovered of the human excavator and trapper as an intelligent and social being, capable of combined labour; and I think that this hypothesis ought not to be rejected, until some more plausible explanation of this remarkable trench and its contents can be offered.

#### EXPLANATION OF PLATES III & IV.

[The original photographs were taken by Mr. Nesbitt, of Blandford, in 1891.]

##### PLATE III.

The elephant-trench at Dewlish, looking north-westward.

##### PLATE IV.

The same, looking south-eastward.

#### DISCUSSION.

The PRESIDENT regretted that the Author, who for so many years had contributed papers to the Society, was unable to be present on this occasion. The paper was really an addition to one which the Author had previously read to the Society on the Dewlish Elephant-Bed; since the publication of the former paper new facts of interest had come to light, which were now recorded.

Dr. HENRY WOODWARD said that he was glad to notice among the exhibits upon the table some eoliths, collected by the Author from the vicinity or from the trench in which the remains of *Elephas meridionalis* were discovered; as, if this elephant had been really a contemporary with early man in Britain, it would be Eolithic man whose weapons we should expect to find. Hitherto, however, there had been no evidence to show that man was a contemporary of *E. meridionalis*, which was a Pliocene species of proboscidean. He was struck by the narrowness of the trench in which the bones were found, and doubted whether a full-sized elephant would have fallen into so narrow a 'pitfall.'

Mr. HUDLESTON enquired whether the remains of many elephants were found in the trench. He had understood hitherto that the remains of only one elephant had been discovered there. From what he had seen of the trench he certainly would never have imagined that it could be of artificial origin. He pointed out that the fall of bones of animals into clefts or fissures in the rocks of the district was no uncommon phenomenon, and it was frequently observed in connection with the Portland Limestone. There was no reason why the same should not also happen in the case of the Chalk.

Prof. SOLLAS thought that the excavation presented a very artificial aspect, but wished for better evidence of its contemporaneity with the elephant. The flint to which special reference had been made certainly appeared to be an 'eolith,' if by that term the exclusion of human agency was implied.

[POSTSCRIPT TO THE DISCUSSION.]

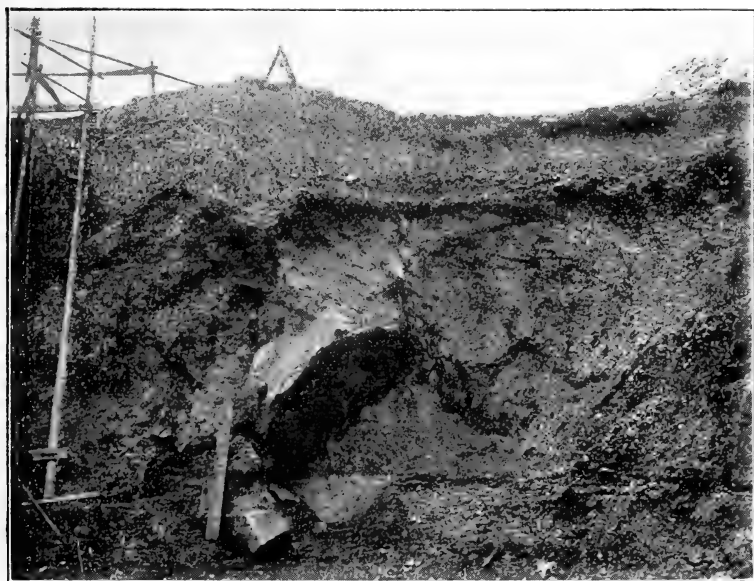
[In reply to Mr. Hudleston's enquiry as to the number of elephants, the AUTHOR points out that nine molars are preserved in museums, and two tusks of different individuals. Many detached plates were also found and much scattered ivory. The heap of white material, shown thrown together in Pl. III, is doubtless ivory. It is said that 'eoliths' were exhibited by the Author: he did not do so wittingly. His specimens were intended to show the character of the gravel with which the trench was found filled up.—*November 25th, 1904.*]



5. SARSEN-STONES *in a* CLAYPIT. By the Rev. E. C. SPICER,  
M.A., F.G.S. (Read November 9th, 1904.)

MIDWAY between High Wycombe and Princes Risborough, above Bradenham, 630 feet above sea-level, there is a plateau which is deeply entrenched by transverse valleys running to the Thames, towards which the plateau is inclined in accordance with the dip-slope. On riding from Lacey Green to Nap Hill through cultivated country plastered by the usual 'Clay-with-Flints,' it appears

*Sarsen-stone embedded in clay, at Walter's Ash.*



surprising to find suddenly in the corn-fields a row of brick-kilns in full operation, among heaps of white stones symmetrically cut into kerbstones and paving-setts, with scattered mounds of white débris, pointing clearly to some features of great geological interest.

The principal pit from which these materials are taken exhibits a structure in remarkable contrast with the surrounding country, as will be seen from the accompanying photograph, which shows a large sarsen-block measuring more than 10 feet across, embedded in a fine, clean, tenacious, grey and reddish clay.

On the opposite side of the pit, which is about 40 yards across and roughly circular, another large stone (half uncovered) lies near

the surface, and slopes towards the centre of the pit. In the foreground is seen what the workmen call the 'rock,' forming a containing-wall for the clay in which the sarsens are embedded. There is no gradation from the 'rock' to the fine clay, and the line of demarcation is clear and hard, the large unworn flints in the 'rock' never protruding into the sarsen-clay, which is free from the admixture of any kind of pebble. It cuts as clean as a cheese. The large flints in the 'rock' are pressed back into it and form a hard, smooth, limiting surface. When the workmen reach the 'rock' they know that profitable operations are over in that direction, and follow the 'head' of clay elsewhere. This 'head' of clay with sarsens sometimes reaches a depth of 50 feet from the surface, as the present pit is expected to do.

At a depth of 30 feet a large block estimated to weigh 50 tons is now being quarried for use in building operations at Windsor Castle. This block is the usual white saccharoidal sandstone with a siliceous cement, and shows no structure except on the weathered edges. In the centre of the pit, another large stone is known to lie under the clay, some 40 feet from the surface. There is a horizontal band of smaller sarsens, measuring  $1\frac{1}{2}$  to 2 feet across, extending athwart the pit above the large blocks. Some 6 feet above them a short band of smaller sarsens, curiously blackened, lies about 3 feet from the surface, looking like remnants of old workings. On the opposite side of the pit appears a long disc-shaped band of fine gravel in clay, bounded above and below by a layer of coarse worn flints and containing a lenticular sarsen of small size. Midway between these and on the same level is a larger subangular sarsen, measuring more than a yard across, containing a 'pot-hole.'

There are therefore in this pit (as in all those adjoining) three distinct formations:—

- (1) The 'rock,' or containing-wall, consisting of the ordinary Clay-with-Flints of the country, the flints being large and unworn.
- (2) The fine clay from which the bricks are made, containing the huge blocks of tumbled sarsens (one of which is said to have weighed over 200 tons); and on the summit of this fine grey or reddish, homogeneous, tenacious clay there is:—
- (3) A thickness of roughly-mingled material, containing horizontal bands with worn flint-pebbles and drifted sarsens of smaller size.

Further enquiry and observation revealed a remarkable fact. Each 'head' of clay would fit roughly into a kind of crater or funnel-shaped depression in the containing 'rock' of clay with large unworn flints, so that if the pits remained open after working had ceased and the pit-owners were not obliged to fill them in, the ground would present a kind of lunar surface pitted on the plateau with a number of irregular conical depressions, having hard smooth sides consisting of large flints thickly embedded in clay. The explanation,

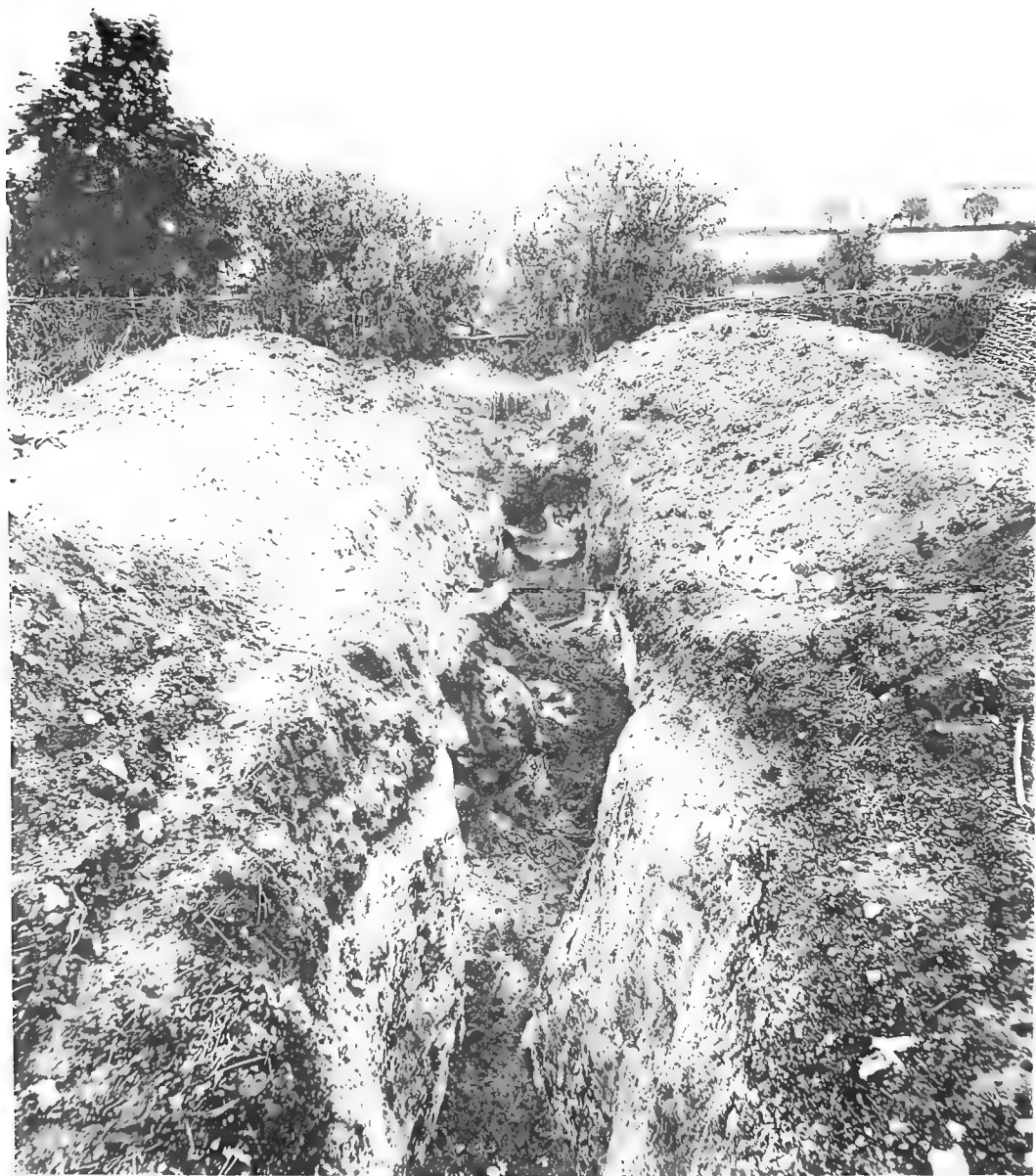


*Benrose, Colo.*

THE ELEPHANT-TRENCH AT DEWLISH, LOOKING N.W. 1891.

*Nesbitt, Photo.*





*North, Chas.*

*Barnes, Celia.*

THE ELEPHANT-TRENCH AT DEWLISH, LOOKING N.W. 1891.





*Nesbitt, Photo.*

THE ELEPHANT-TRENCH AT DEWLISH, LOOKING S.E. 1891.

*Bemrose, Colla.*

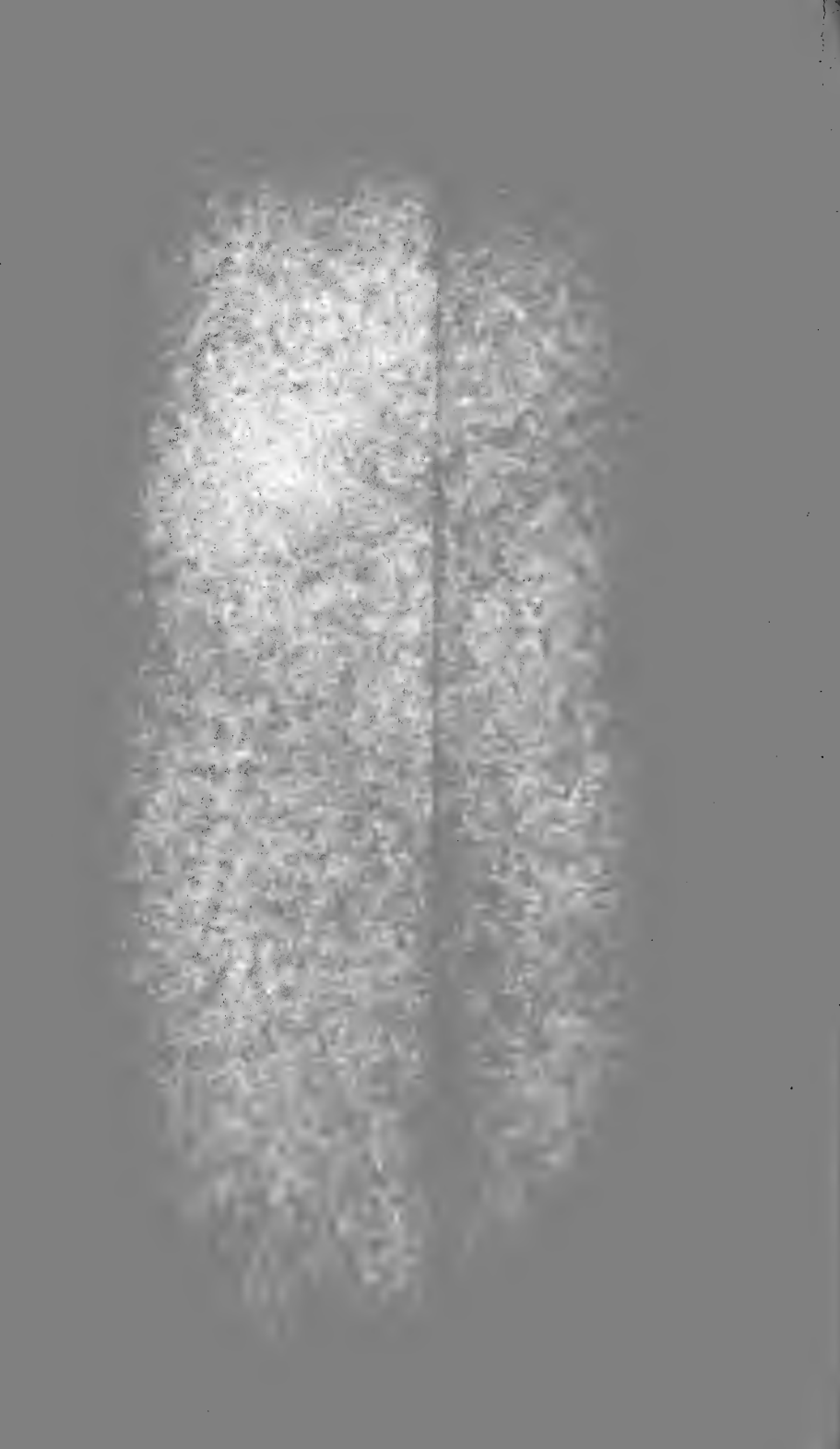






Q. 6. J. 1. G. 1. 5. 1. Vol. LXI. Pl. IV

THE ELEPHANT-TRENCH AT DEWLISH. LOOKING S E 1391.



then, seemed clearly that we are dealing here with swallow-holes formed by underground solution in the Upper Chalk. The flints sank downward by superincumbent pressure against the sides and bottom of each, and the inflowing ooze of wet clay gave way beneath the heavy sarsen-blocks, which sank deeply into it. For the sarsens in clay show this remarkable arrangement:—They slope on all sides towards the centre of the pits, and at the bottom they are horizontal, and the quarrymen work the pits with this observed fact to aid them. The original containing-walls of the swallow-holes were Chalk-with-Flints, that by process of dissolution became Clay-with-Flints, the flints (large and unworn, having been subjected to no detrition by movements over any but a very small area) remaining *in situ*, like the flints found at the base of the Thanet Sands, which were clearly never deposited by marine action, but simply ‘remain’ in their old position while the chalk that contained them has disappeared.

In conclusion, I wish to express my thanks to Mr. Bristow, under whose direction the pits are worked, for the help which he courteously afforded me in the pursuit of my investigations.

#### DISCUSSION.

Mr. BARROW drew attention to the deep cuttings on the new railway between Uxbridge and High Wycombe. Near Gerard's Cross the lowest Tertiary deposits (Woolwich and Reading Series) were exposed, and one here saw that a bed of white sand, when followed to a sufficient depth, passed first into isolated and rounded blocks of nearly-white sandstone, and finally into a solid bed. This material was almost certainly the same as that exhibited by the Author. It was clear that this bed, when near the surface, decomposed into loose sand more rapidly than ordinary denudation could remove that sand. Thus the solid bed could never be found in a natural outcrop. But under special conditions, when these beds had once formed a continuous thin sheet above the Chalk, powerful floods or ice in motion had swept away the loose sand and picked up the remaining hard cores, involving them in the general mass of Drift of the country. The truth of the Author's explanation of the inverted-cone shape of the hollows in which the sarsens were found, namely, that they were essentially swallow-holes in the Chalk, was firmly established by the cutting a little farther west of Gerard's Cross. There a continuous series of these inverted cones (swallow-holes) had been cut open, and the basement-beds of the Tertiary rocks passed alternately over the edges and down to the apices of these cone-shaped hollows. Seen from a distance, the beds overlying the Chalk seemed as if they had been affected by some powerful earth-movements. The sections were so striking that they ought to be photographed.

Mr. WHITAKER said that, 40 years ago or so,<sup>1</sup> he had published a brief description of pits like those now described by the Author, and they were then, as now, worked for the greywethers which were used as building-material for Windsor Castle. The source of such greywethers was not confined to one horizon of the Lower Tertiary, and he had actually seen Eocene sandstone of Reading age in place. He thought that no other explanation of the facts than that given by the Author would hold good.

Prof. SOLLAS said that he had visited the pits described, under the guidance of the Author, and was glad to be able to concur with him in his conclusions as to the history of the sarsens. He thought that the more superficial deposits of the pits might require further explanation, and would not be surprised to find that ice in some form had played a part in their formation.

Mr. W. P. D. STEBBING, in commenting on the paper and on Mr. Barrow's remarks, mentioned that the irregular dissolution of the Chalk of the North Downs (as seen in sections at Tadworth on the Chipstead-Valley Railway) had caused the Lower Tertiary formations above to sink into the hollows between the upstanding pinnacles of Chalk, and so, in the long railway-cutting, to give the effect of a wave-like contour to these beds. He also mentioned the cutting-through by this railway of a small bowl-shaped mass of pure white sand, which under certain past conditions might have been cemented into a sarsen-stone, and then would have occurred in the section just as those observed by the Author in the Chilterns.

Dr. SALTER referred to similar deposits at Hyde Heath, near Chesham, in which big polished blocks of pebbly greywether are found. At Ayot Brickyard (Hertfordshire), the Eocene deposits dip down into huge pipes in the underlying Chalk.

[<sup>1</sup> 'Geology of Parts of Middlesex, Herts, Bucks, &c.' Mem. Geol. Surv. (1864) pp. 66, 71.]

Sir Joseph Prestwich regarded the greywethers of this region in Buckinghamshire as belonging to the Reading Series. He mentioned that 'on the Chalk-hills above Bradenham, 3 miles northward (of High Wycombe), sandstone-blocks are very numerous, and, although enveloped in a ferruginous clay-drift, they are, I believe, nevertheless, nearly *in situ*.' In a footnote he specifies Walter's Ash and Napple Common Quart. Journ. Geol. Soc. vol. x (1854) p. 127.—Ed.]

6. *On an OSSIFEROUS CAVERN of PLEISTOCENE AGE at HOE-GRANGE QUARRY, LONGCLIFFE, near BRASSINGTON (DERBYSHIRE).* By HENRY HOWE ARNOLD-BEMROSE, J.P., M.A., F.G.S., and EDWIN TULLEY NEWTON, F.R.S., V.P.G.S. (Read November 23rd, 1904.)

## [PLATES V-VIII.]

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## I. INTRODUCTION.

IN April 1902, the south-south-eastern end of a cavern in the Hoe-Grange Quarry was broken into, in the course of the quarrying-operations (Pl. VI). The discovery was first made known to us by Mr. J. Ward, Curator of the Cardiff Museum, who was formerly a resident in Derby, and has worked out several caverns in the neighbourhood. One of us visited the quarry on April 26th, 1902, and subsequently, through Messrs. Holland & Rigby, solicitors (of Ashbourne), obtained leave from Major Nicholson, the owner of the quarry, to work the deposits on behalf of the Derbyshire Archæological & Natural History Society. The owner stipulated that the cavern should be worked in such a manner as would secure the largest amount of evidence possible under the circumstances. In company with Mr. C. Fox-Strangways we visited the quarry, and found that the cavern had been indiscriminately worked in the upper part, above the line AB in the horizontal section (Pl. V, fig. 1), for a distance of 34 feet north-north-west of the point where the quarrymen had first broken in at the south-south-eastern end. Our thanks are due to Messrs. Shaw & Lovegrove, the lessees of the quarry, who did their best, before we took the work over, to secure and retain, as far as they could under the circumstances, specimens which had been obtained. By this means they supplied us with 1577 specimens, and we subsequently recovered other 679 specimens from the tip-heaps. Some of these were obtained by sifting the deposit in water; others were picked out by the quarrymen. All these specimens have been labelled 'General,' because they were obtained previous to the time when we worked the cavern systematically (Table I, col. G, p. 58).

As soon as the discovery became known, the locality was visited by numerous ardent collectors, some of whom came even at night-time; and many specimens were taken away, despite the efforts made

by Messrs. Shaw & Lovegrove to prevent their loss. The foreman, Mr. George Walton, rendered us very great help, and so far as possible arranged the work of the men under him to suit our requirements. Messrs. Shaw & Lovegrove also provided quarrymen and labourers to carry on the excavations, which were paid for from funds collected mainly from Derby, Buxton, Bakewell, and Matlock. The excavating-work was for the most part carried out under the direction and supervision of one of us; but Mr. Storrs Fox, of Bakewell, visited the cavern a number of times in 1902, and on several occasions superintended the work.

In July 1902, we decided to suspend operations until the quarry-face had been worked farther back, parallel to the length of the cavern, in order that the deposits might be worked at a lower level than that of the line AB in the horizontal section (Pl. V, fig. 1).

## II. THE PRESENT PHYSICAL CONDITIONS OF THE DISTRICT, AND A DESCRIPTION OF THE QUARRY.

The Hoe-Grange Quarry (6-inch Ordnance-Survey map, xxxiii S.E.; 1-inch Geological-Survey map, 72 N.E.) is close to the High Peak Railway, about a quarter of a mile north-west of Longcliffe Station (which is on the road from Matlock to Ashbourne) and a little more than a mile north-west of the village of Brassington. It is situate on the south-eastern portion of the Mountain-Limestone plateau, which extends from near Wirksworth on the south-east to Buxton on the north-west, at a height varying from 1000 to 1200 feet above Ordnance-datum. This portion of the plateau forms the water-parting between the rivers Bradford and Wye, tributaries of the Derwent near Darley Dale, on the north-east, and Bletch Brook, Bradbourne Brook, and Bentley Brook, tributaries of the Dove near Ashbourne, on the south-west. The quarry is being worked back into the south-western slope of the plateau. The bottom of the quarry (into which runs a siding from the High Peak Railway) is 1090 feet above Ordnance-datum, and the top of it is about 30 feet higher.

If we stand on the top of the quarry, it is obvious that we are standing on the edge of the limestone-plateau, and that the quarry is cut in the south-western face of a small knoll or hillock on that plateau. It is separated from another knoll on the north by a small depression, which widens out into a valley lower down on the south-western slope, and from Harbro' Rocks (1244 feet above Ordnance-datum) by a small depression at Longcliffe Station, which point forms a col at a height of 1057 feet above Ordnance-datum.

The upper beds in the quarry consist of cherty limestone, and the lower ones of more massive limestone. Some portions are completely dolomitized along the joints; but the lowest bed is a pure white limestone, used for making limestone-setts. The highest point of the hillock in which the quarry is situate is about 30 feet higher than the top of the swallow-hole mentioned below, and is a short distance nearly due east of it.

There are several joints in the quarry which run in a north-north-westerly and south-south-easterly direction. The cavern is evidently a master-joint enlarged by the action of water. A joint, 5 feet to the north-east of the cavern and farther back in the quarry, was found after our first year's operations, but no bones were discovered in the clay with which it was filled.

### III. THE METHOD OF WORKING THE DEPOSITS, AND THE RESULTS OBTAINED.

Before the cavern was discovered, various parts of the quarry, including that in which the cavern was found, had been let on 'bargain' or piecework to the quarrymen. We had, therefore, to carry on the excavations in such a manner as to fall in with these arrangements, by first removing a portion of the deposit from the cavern and then allowing the men to remove the cavern-wall up to the point to which we had worked. Careful measurements were made and levels obtained during the progress of the work, and such bones from each layer or part of the cavern, as it seemed necessary at the time to keep separate, were packed in different boxes. During 1902 we explored the upper part of the cavern, above the line AB in the horizontal section (Pl. V, fig. 1), and during 1903 the part below this line.

Previous to our first visit to the cavern, the deposits had been indiscriminately worked to a distance of 34 feet from the point where the men first broke into it, and to a depth of about 9 feet below the cavern-roof. The outer or south-western wall of the cavern to this depth, and for a distance of about 27 feet, had also been quarried away. At our first visit, therefore, the cavern-entrance was 27 feet from the point where the men broke in, and the deposit had been cleared away from what was then the inside of the cavern for some  $6\frac{1}{2}$  feet in a north-westerly direction.

We commenced operations by fixing a wooden door (Pl. VI, fig. 1) at the entrance to keep out intruders, had the face of the deposit cleared, and obtained the following section:—

#### SECTION MEASURED ON MAY 13TH, 1902.

$6\frac{1}{2}$  feet north-north-west of the wooden door, and above the line AB in Pl. V, fig. 1.

		<i>Feet inches.</i>	
No. I.	Layer of surface-soil, with angular fragments of limestone and few bones .....	0	6
No. II.	Yellowish sandy clay, showing traces of lamination and containing bones .....	2	0
No. III.	Breccia, rich in bones; consisting of bones and lumps of limestone, often cemented into a hard mass, especially on the south-west side of the cavern; softer on the north-west side .....	2	0
No. IV.	Clay, with large angular blocks of limestone and bones .....	1	2
No. V.	Dark moist clay, with few bones; bottom not reached .....	1	0
		6	8

Layer No. I (Pl. V, fig. 1) was here 2 feet 5 inches below the roof of the cavern. The layers were not horizontal, but dipped south-south-eastward, so that as we worked farther into the cavern towards the north-north-west they rose, and at a distance of 15 feet from the door layer No. I was touching the roof. These layers, with the exception of No. V, were traced to a distance of 18 feet from the door. They then became so indistinct that it was impossible to trace them farther. At 20 feet from the wooden door we reached the fissure or swallow-hole. The 142 bones from these 2 feet (namely, between 18 and 20 feet from the door) were therefore kept separate (Table I, col. 8, p. 58). The 2 feet of deposit (measured horizontally) consisted of clay with bones and large angular blocks of limestone. At a distance of 16 feet from the door we found a layer of stalagmite, 1 to 3 inches thick, and below it an angular limestone-gravel cemented together in places by carbonate of lime. Neither of these layers contained bones; but 138 bones were obtained from the clay immediately above the stalagmite, and, as we could not correlate this clay with any of the other layers, the bones from it were kept separate (Table I, col. 6). The stalagmite-layer extended for a distance of about 12 feet to the north-north-west: at 16 feet from the door it was 3 feet below the top of breccia No. III. As the breccia was 2 feet thick and layer No. V was 14 inches thick, this layer No. V had apparently thinned out. Layers Nos. 6 & 8 were very near together, the bones from No. 8 being obtained from a place about 2 feet above those from No. 6.

#### Entrance or Swallow-Hole.

The width of the swallow-hole, which communicated with the ground-surface near the top of the quarry, measured in the same direction as the length of the cavern, was  $7\frac{1}{2}$  feet; and from this 980 bones were obtained (Table I, col. 7), all above the line AB in Pl. V, fig. 1. The upper part of the material filling the hole consisted of large masses of cherty limestone with clay, and rested upon the stalagmite (Table I, col. 6) to the south-south-east. In the north-north-western portion of the swallow-hole only three layers could be distinguished, namely, (1) clay, (2) clay with bones, and (3) gravel (angular). The layers in the swallow-hole formed a slight anticline, dipping south-south-eastward and north-north-westward. To the north-north-west of the swallow-hole only about ten bones were obtained; the deposits in that direction consisted of clay with large blocks of limestone, and a hard rubble with pieces of chert. Some 17 feet north-north-west of the swallow-hole, the cavern narrowed to a width of 2 or 3 feet, and a short distance farther on died out into a small joint.

A ground-plan of the upper part of the cavern, along the line AB in the horizontal section, is reproduced in Pl. V, fig. 2.



## Lower Level, below the line AB. (Pl. V, figs. 1 &amp; 3.)

In 1903, after the whole of the upper part of the cavern above the line AB had been removed, we proceeded to work on the lower level, between the lines AB and CD (Pl. V, fig. 1), commencing at the south-south-eastern end. A number of bones were found under the spot where the wooden door had been fixed in the previous year. Although we could not definitely trace the connection, this deposit seemed to be part of the upper layers Nos. I & V, if indeed it was not really a part of No. V. North-north-west of this point (below the door) no bones were obtained, until we had worked 45 feet to the north-north-west; then a number were found in a clay (No. 11), which was above another bedded clay (No. 12), dipping at a high angle, underneath which was a well-bedded sand (No. 13), about 5 feet thick. Under this sand was a deposit of black 'wad' (No. 14). This 'wad' was worked down to a depth of about 15 feet, and was found to rest upon a clay (No. 15). The other parts of the cavern at the lower level, except those just mentioned, were filled with clay and rubble, and contained no bones. Near No. 11, beneath the bone-bearing beds, were found lumps of breccia with *Helix*-shells, and also a number of concretions of magnesian limestone. We believe that such concretions have never been found among the dolomitized limestones of the district, and may therefore have come from a distance. An examination of the horizontal section and the two ground-plans (Pl. V, figs. 1-3) shows that the cavern was about 120 feet long, and that at both ends it narrowed down to a vertical joint at the level AB; also, that at the south-south-eastern end this narrowing continued at the lower level CD, but that the cavern did not thin out so rapidly north-north-westward at the lower level as it did at the higher one. In the wall of the fissure at the south-south-eastern end of the lower level, about 6 feet north-north-west of the place where the cavern was first broken into, fifty bones were found, consisting mainly of rabbit, with only one bone of a carnivorous animal, namely, *Hycena*. It is impossible to correlate these few bones with those from the other layers, so we have placed them separately in Table I, col. 10 (p. 58). The bottom of the cavern was reached at the south-south-eastern end, but deepened north-north-westward to an unknown extent. It was found possible, for economic reasons, to trace the beds at the north-north-western end of the cavern some 15 feet into the wad. But, as very few bones were found in the layer between AB and CD, and none in the deeper excavations at the north-north-western end, it was decided not to continue the exploration any farther.

## Summary of Results.

Although the rubble and clay in many parts of the cavern showed no signs of stratification, there appear to have been three distinct groups of deposits. The upper deposits, which include layers I to 9, contained by far the majority of the bones. They were probably

introduced mainly through the swallow-hole. The second group of deposits, consisting of clay and rubble, with a few bones in places (No. 11), was below the first group. The third and lowest group, found to the north-north-west, consisted of bedded clay (No. 12), sand (No. 13: quartz-grains, well rounded), and wad (No. 14); the whole dipped at an angle of  $40^{\circ}$  to  $45^{\circ}$  south-south-eastward, and contained no bones. It therefore seems that there were three main groups of deposits which were formed at various times, although there is no break of continuity between them. Some of them probably found their way through the master-joint at different points. We cannot say definitely which is the oldest deposit, though from their relative positions it seems probable that the 'wad,' sand, and bedded clay were deposited first from a north-north-westerly source; that from a somewhat similar source, or from numerous openings along the joint, the clay and rubble were introduced, and augmented by blocks which fell from the roof of the cavern from time to time; and that finally, at a later period, the majority of the bone-bearing beds were deposited, mainly through the swallow-hole.

#### IV. DESCRIPTION OF THE MAMMALIAN AND OTHER REMAINS.

##### Carnivora.

*FELIS LEO*, Linn. (Lion.) (Pl. VII, fig. 1.)

Among the many mammalian bones which have been recovered from this cave none, perhaps, are more interesting than those of the lion. One of these specimens is the ramus of a lower jaw of a young animal, and besides this there are parts of the fore and hind feet of one or more adult animals. The first-named specimen is an imperfect left ramus, with the milk-molars 3 and 4 still in place (Pl. VII, fig. 1), the latter showing the characteristic small, adpressed, hinder cusp. The germ of the first permanent molar (or carnassial tooth of the adult series) is to be seen within the substance of the jaw. The foot-bones indicate a big animal; but they are not so large as those figured by Prof. W. Boyd Dawkins in the Palæontographical Society's Memoir. Two metacarpals, a cuboid, and an astragalus have each the characteristic feline form, and a penultimate phalange shows the hollowed side for the retracted claw. These remains can be unhesitatingly referred to the lion.

Some of these leonine bones were obtained before particular notice had been paid to the different layers in the cave; but others were met with, deep in the undisturbed beds: one specimen was found in layer No. IV and others in the lower stratum, below the door, No. 9. (See the horizontal section, Pl. V, fig. 1.)

*FELIS CATUS*, Linn. (Wild Cat.) (Pl. VII, figs. 2 & 3.)

Remains of the wild cat are known to occur in British caves, but they are by no means of common occurrence. It is interesting,

therefore, to find among the Longcliffe specimens several limb-bones referable to this species. Although no teeth or parts of the skull were met with, the limb-bones are unmistakably those of a cat. The straight femur, the angular shaft of the tibia, the perforated humerus, as well as the forms of the metatarsal and metacarpal bones, agree precisely with the corresponding parts of a large cat. These bones are much bigger than those of an ordinary domestic cat; but they agree in length and form with those of a male European wild cat in the Museum of the Royal College of Surgeons.<sup>1</sup> They are, however, much stouter, and indicate an animal of very robust proportions. The bones which have been recovered are parts of a humerus, a radius, an ulna, and a metacarpal, also an ilium with the acetabulum, two femurs, a tibia, and two metatarsals.

MEASUREMENTS OF THE FEMUR AND TIBIA OF THE WILD CAT, IN MILLIMETRES.

Femur, greatest length.....	136·0
Do. least circumference .....	33·0
Tibia, greatest length .....	146·0
Do. least circumference .....	31·5

It is just possible that these bones belonged to one animal, and they were all found in the lower stratum; but, seeing that some of them were found towards the south-south-eastern end (No. 9), and others towards the north-north-western end (No. 11), that is, 45 feet apart, this is uncertain.

Besides the above-mentioned bones of wild cat, there is one ulna of a much smaller cat, which was found above the stalagmite-floor (No. 6), that is, some 13 feet above the wild cat's remains.

HYÆNA CROCUTA, Erxleben. (Spotted Hyæna.)

The remains of *Hyæna* are much more abundant in this cave than are those of any other carnivore; indeed, if we except *Bos* and *Cervus*, *Hyæna* is better represented than any other genus. Portions of jaws, teeth, and bones from all parts of the skeleton have been obtained, some in a very perfect condition, as well as coprolites; but the latter not very abundantly. Further evidence of the presence of living hyænas is to be seen in the gnawed bones of other animals which have been found.

The hyæna-bones themselves need no special description: they evidently belong to the form so generally met with in caves, which has been called *Hyæna spelæa*, but is now believed to be the same as the living African spotted form, *Hyæna crocuta*. Remains of *Hyæna* have been met with in all parts of this cave where bones have been found, and in every layer between No. I and No. 11.

CANIS LUPUS, Linn. (Wolf.)

This species is represented by four metapodial bones, which, at

<sup>1</sup> We desire to take this opportunity of thanking Prof. Charles Stewart, the courteous Curator of the Hunterian Museum of the Royal College of Surgeons, for the facilities which he has afforded us, on this and many other occasions, for the examination of the unique osteological collection under his charge, as well as for valued help in the solution of some difficult osteological problems.

first sight, resemble those of the hyæna; but they are more slender, and the proximal articular surfaces are different. It is probable that these few bones represent at least three animals, for they were found at different times and at three different horizons, namely, Nos. II, IV, & 8.

**VULPES ALOPEX**, Linn. (Common Fox.)

The only specimen that can be referred to this species is a lower carnassial tooth, rather broader proportionately than is usual, but agreeing in this particular with a tooth in a lower jaw of this species from the fissure at Ightham, in Kent. The present tooth was found in the swallow-hole (No. 7).

**URSUS HORRIBILIS** (?) Ord. (Grisly Bear.) (Pl. VII, fig. 4.)

Remains of bears have been met with in nearly every stratum between Nos. II and 9. Some of these evidently belonged to animals of great size; but none so big, or presenting such characters, as to justify their reference to the cave-bear, *Ursus spelæus*.

Most of the remains are foot-bones, but portions of humeri and several teeth have also been found. Unfortunately, we possess no example of the characteristic lower fourth premolar tooth. A left maxillary bone, with the two hindmost teeth in place, is in the possession of Mr. W. Storrs Fox, of Bakewell. The first tooth of this specimen (molar 1) measures 23·5 millimetres in length and 17·5 mm. in width. The hinder tooth (molar 2) is 41·0 mm. long and 18·5 mm. wide; it is comparatively long and parallel-sided, and the hinder end is less pointed than usual. The jugal process of this maxillary bone arises opposite the middle of the last molar, and in this respect resembles the grisly bear rather than the cave-bear.

We have a last lower molar of moderate size (length = 23 mm., width = 17 mm.), which is pointed posteriorly, and in this respect is not unlike some examples of *Ursus spelæus*, but we think it more likely to belong to *U. horribilis* (Pl. VII, fig. 4).

Although we can point to no very positive evidence that some of these remains may not belong to small examples of cave-bear, we do not think it at all likely; it seems more probable that they belong to either the grisly or the brown bear, and on the whole we prefer to refer them provisionally to the former, *Ursus horribilis*.

**MELES TAXUS**, Schreber. (Badger.)

The badger is represented by two bones only, an ulna of a young animal wanting its epiphysis, and a metapodial of an adult. The horizon of one of these is uncertain, but the other was found in the south-south-eastern part of the lower level.

### Cheiroptera.

**VESPERTILIO (PLECOTUS) AURITUS** (?) Linn. (Long-Eared Bat.)

The distal half of a humerus of a bat agrees in size and form with that of the long-eared bat, and is with doubt referred to that species. It was found in the north-north-western lower layer, No. 11.

## Ungulata.

## Bos or BISON.

Bovine remains were more numerous in the Longcliffe Cave than those of any other animal; they include bones from all parts of the skeleton, but unfortunately there are no portions of the frontal bones and horn-cores sufficiently perfect to indicate the species positively. Many of the bones and teeth are of large size, and would compare favourably with the largest bovine remains that have been found in Pleistocene deposits. There is, however, much variation in this respect, even among the bones that are obviously adult. Many young animals are represented, not only by limb-bones without epiphyses, but also by numerous milk-teeth.

It is by no means easy to decide the species to which these bovine remains should be referred, or whether they represent more than one species. Differences in the proportions of some of the bones are obvious, such as would seem to show that two forms of large size are present, and one is naturally led to expect *Bos bison* and *Bos primigenius*; but a closer examination makes one less certain that there are two species. The most obvious differences are seen in the proportions of the metatarsal and metacarpal bones, more especially in the latter. Some of these are exceedingly wide, while others, that are absolutely longer, are actually narrower.

A comparison with the measurements of metacarpals, as given by William Davies<sup>1</sup> in his Catalogue of the Antonio-Brady Collection, shows that our broad form agrees very closely with what he has referred to *Bos primigenius*, while our more slender form is the counterpart of his *Bison*.

MEASUREMENTS (IN MILLIMETRES) OF METACARPALS FROM LONGCLIFFE CAVE, COMPARED WITH THOSE GIVEN BY W. DAVIES, AND BY PROF. BOYD DAWKINS.

	Greatest length.	Least width of shaft.	Width of proximal end.	Width of distal end.	Per cent. width to length.
Bison (?) from Longcliffe (No. 40) .....	9.75	1.7	2.85	3.15	17.4
<i>Bos primigenius</i> (?) Longcliffe (No. 41) .....	9.3	2.2	3.7	3.5	23.6
Bison, Ilford, <i>ex</i> Davies. <i>Bos primigenius</i> , Ilford, <i>ex</i> Davies .....	9.7	1.7	3.0	3.0	17.4
	10.0	2.2	3.6	3.7	22.0
Bison, Windy Knoll, <i>ex</i> Dawkins, extremes.	9.3	2.2 *	3.4	3.7	23.6
	8.7	1.6 *	2.8	2.8	18.3
Bison, from Pleasley Vale, in Mus. Pract. Geol.	8.25	1.63	2.8	3.0	19.7

\* These measurements are calculated from the circumference.

<sup>1</sup> 'Catalogue of the Pleistocene Vertebrata from the Neighbourhood of Ilford, in the Collection of Sir Antonio Brady' London, 1874, pp. 46 & 55. [Privately printed.]

It seems, from the foregoing comparative measurements, that the two forms may be present in the Longcliffe Cave. When, however, these bones are further compared with the extreme measurements of the large series of bones from Windy Knoll given by Prof. W. Boyd Dawkins,<sup>1</sup> all of which he refers to *Bison*, one feels much less certain that the two species can be identified by their metacarpal bones.

The metacarpal bone of an undoubted *Bison*-skeleton from Pleasley Vale (Derbyshire), preserved in the Museum of Practical Geology, Jermyn Street, is proportionately rather wider than the more slender Longcliffe specimens; indeed, it comes about halfway between the two forms, and, further, lends support to Prof. Boyd Dawkins's determination when he refers all the Windy-Knoll bovine remains to *Bison*. This, however, leaves us in the difficulty with which we began, namely, the need of characters by which to distinguish the limb-bones of *Bos* from those of *Bison*.

Bovine remains have been met with in every stratum of the Longcliffe Cave, from No. I to No. 9.

*CERVUS GIGANTEUS*, Blumenb. (Great Irish Deer.) (Pl. VIII, figs. 1 & 5.)

Only a few bones and teeth of this large deer have been found, but fortunately these leave no doubt as to the species being present in the cave. A series of six upper grinders in the maxillary bone is the most important of these remains; two large cervine metacarpal bones are, however, equally characteristic of the species. A big astragalus, that at first sight might be mistaken for one of *Bos*, has the wide, clearly-marked, oblique groove of the distal articulation, which seems to separate the astragalus of *Cervus* from that of *Bos*.

One of the above-mentioned specimens came from layer No. III, but the horizon of the others is uncertain.

*CERVUS ELAPHUS*, Linn. (Red Deer.) (Pl. VIII, fig. 2.)

Although cervine bones and teeth are very numerous in this cave, comparatively few can be referred to the red deer. Limb-bones of a large size, including tibias, metacarpals, metatarsals, and other foot-bones, indicate a deer apparently larger than the ordinary red deer as we now know it, but doubtless belong to this species.

Such fragments of antlers as have been found cannot be positively referred to this species; most, if not all, of them agree better with the fallow-deer. All the specimens that can be definitely termed red deer were found in the upper layers between No. I and No. 8.

*CERVUS DAMA*, Linn. (Fallow-Deer.) (Pl. VII, fig. 6, & Pl. VIII, fig. 3.)

By far the greater number of the deer-bones and teeth from this cave are of such a size, that, had they been found in a recent deposit, they would, with little hesitation, we think, have been regarded as

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 247.

parts of fallow-deer; but, seeing that they accompany Pleistocene species and that fallow-deer has not hitherto been recorded as a British Pleistocene form, it becomes necessary to examine these remains much more carefully; and then it is that some doubts arise as to the possibility of their belonging to small red deer.

Bones from all parts of the skeleton are present, including portions of antlers with frontals, but none of these are sufficient to define the species. The small size as well as the curve of the beam immediately above the burr, in one or two examples, seem more like *Cervus dama* than *C. elaphus*, but one hesitates to speak positively. The numerous grinding-teeth are all small for *C. elaphus*, although some few agree fairly well with those of a female red deer. On the other hand, the cheek-teeth of a fair-sized male fallow-deer are so nearly the same as those of a female red deer, that isolated teeth could scarcely be identified. The limb-bones present us with similar difficulties: for the most part, they agree in size with the fallow-deer, and are too small for the red deer; but there are others which are intermediate.

However, a large number of these teeth and limb-bones appear to us to be too small for red deer, and can only, we think, be parts of fallow-deer. If, then, we are compelled to accept certain of these remains as definite

COMPARATIVE MEASUREMENTS (IN MILLIMETRES) OF THE TEETH OF RED AND FALLOW-DEER.

	Fallow-deer, ♂. E. T. N.	Fallow-deer, ♂. Roy. Coll. Surg., 1537.	Red Deer, ♀. E. T. N.	Red Deer, ♀. Roy. Coll. Surg., 1496.	Red Deer, ♂. Roy. Coll. Surg.	Hoe Grange: Nos. 2050, 2909 (Pl. VII, fig. 6), & 254, 3925.
	Outside length, front to back.	Width, side to side.	Length.	Width.	Length.	Width.
Upper M 1	15.5	15.5	19.5	19.0	19.8	18.0
Do. 2	18.5	17.0	20.7	22.5	22.6	19.8
Do. 3	18.5	16.5	19.5	23.0	21.8	19.0
Lower M 1	15.0	9.8	...	16.6	20.0	16.0
Do. 2	17.0	10.0	...	21.5	23.0	19.0
Do. 3	21.5	10.5	...	28.2	31.5	24.5
				12.0	13.0	10.0
				13.5	15.0	11.0
				13.0	14.0	11.5

evidence of fallow-deer in this cave, it seems highly probable that a large proportion of the remains discussed, under the heading of this species, are referable to the same.

The fallow-deer has not been recorded from any undoubted Pleistocene deposit in Britain, and its presence in this cave at once suggests a recent origin for the deposits. We think, however, that the physical conditions show this to be untenable (see p. 44).

Prof. W. Boyd Dawkins<sup>1</sup> says that the fallow-deer

'was probably introduced by the Romans, since its remains occur in refuse-heaps of Roman age, . . . while it has not been met with in older deposits.'

We must bear in mind, however, that the same writer had previously described the closely-allied *Cervus Browni*<sup>2</sup> from the Pleistocene of Clacton; this we only know by its antlers, and, although it may otherwise be indistinguishable from *C. dama*, we cannot refer our specimens to that species.

The remains which we here refer to fallow-deer were found at every horizon in the cave from which bones have been obtained.

#### CAPREOLUS CAPREA, Gray. (Roebuck.) (Pl. VIII, fig. 4.)

There are a few bones that can be accepted with more or less certainty as representing this species; these include metacarpal, metatarsal, and other foot- and limb-bones, with perhaps one or two pieces of antlers.

These specimens were found in upper layers at Nos. III, IV, & 7, and also in the lower layer at No. 9.

#### SUS SCROFA, Linn. (Wild Boar.)

Only four specimens belonging to this species have been found; one of these is a large upper second molar, the crown of which measures 36 millimetres in length and 22 mm. in width, and indicates a fully-adult animal of large size. A right lower second molar, corresponding in size to the upper tooth just mentioned, measures 24 mm. in length and 16.5 mm. in width.

The exact horizon of these teeth is not known, but the other two representatives of the species were found in layer No. II, and in the south-south-eastern lower layer (No. 9).

#### RHINOCEROS LEPTORHINUS, Owen.

The remains of *Rhinoceros* have been found rather plentifully, and include most parts of the skeleton; they are, however, all more or less broken. This imperfection may be due, in some degree, to the carelessness of the workmen.

We have been fortunate in securing two examples of the rare first upper premolar, besides other premolars, molars, and milk-teeth. These teeth are of the characteristic *leptorhinus*-form, and nothing has been detected that would point to the presence of *Rhinoceros antiquitatis* in the cave. Both species have been met with in British caves, and sometimes they have been found together.

<sup>1</sup> 'Cave-Hunting' 1874, p. 77.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxiv (1868) p. 511.



Recently there has been some question as to the propriety of using the name of *Rh. leptorhinus* for this species of *Rhinoceros*, rather than *Rh. hemitechus* as was done by Falconer. The question was fully discussed by Prof. W. Boyd Dawkins,<sup>1</sup> and for many years the former name has been adopted in this country. There is no doubt as to the British forms called by Owen *Rhinoceros leptorhinus* being the same species as those for which Falconer proposed the name of *Rh. hemitechus*; but the synonymy of the Continental forms is a much more complex problem, the solution of which will not be attempted here; the matter is only referred to, for the purpose of making it clear that the species found in the Longcliffe Cave is that for which the two names above mentioned were used respectively by Owen and Falconer.

*Rhinoceros*-remains have been met with in all the upper layers (Nos. II-8) except the topmost, and in the south-south-eastern lower layer (No. 9).

**ELEPHAS ANTIQUUS**, Falconer. (Straight-tusked Elephant.) (Pl. VII, figs. 5 & 5 a.)

Only a single specimen has been found, to indicate the presence of this species: and this is one half of a third milk-molar, with three plates and a talon preserved. The greatest length of this tooth is 44 millimetres, its greatest width 31 mm., and the length of the parts preserved is 33 mm. The enamel, where seen, is very coarsely wrinkled, but a cap of cement extends a good way down the sides of the crown. The tips of one or two points of the plates are just appearing through the cement. The base is very open, the plates seeming to consist of little more than the enamel, with but a slight infilling of dentine, showing that the tooth was not fully formed and that the animal was a young one.

This tooth was found in layer No. III.

### Rodentia.

**LEPUS CUNICULUS**, Linn. (Rabbit.)

A number of bones, seemingly parts of one skeleton, were obtained from the fissure at the south-south-eastern end of the cave (No. 10); and a few others were found in layers Nos. I, II, & III.

**LEPUS** sp. (Hare.)

Two metapodial bones are probably referable to the common hare; one of these was from the south-south-eastern lower layer (No. 9).

**MICROTUS (EVOTOMYS) GLAREOLUS**, Schreber. (Bank-Vole.)

This species is represented by an upper anterior cheek-tooth with fangs and an incisor, as well as by two or three humeri, which

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 213.

- in size agree best with this species. These, in common with most of the small vertebrates, were found with the rabbit-bones in the fissure at the south-south-eastern end of the cave (No. 10).

*MICROTUS AGRESTIS* (?) Linn. (Field-Vole.)

Two incisor-teeth and three limb-bones, which are larger than those of the bank-vole and agree in size with those of *M. agrestis*, are, with doubt, referred to this species. They are from the south-south-eastern fissure (No. 10).

*MICROTUS AMPHIBIUS* (?) Linn. (Water-Vole.)

Part of a lower incisor-tooth, which is too large for any of the above-mentioned species and too small for the common rat, most probably belongs to this species. Its horizon is uncertain.

*LEMMUS LEMMUS* (??). (Norway Lemming.)

The middle portion of a tibia intermediate in size between the tibia of *Microtus agrestis* and that of *M. amphibius*, but agreeing in this particular with the Norway lemming, may indicate the presence of this northern form, which we know was living even farther south in this country in Pleistocene times.

*MUS SYLVATICUS* (?) Linn. (Long-Tailed Field-Mouse.)

Among the remains of small rodents is one perfect tibia, which agrees most closely with that bone of the field-mouse. It was discovered in the lower north-north-western layer (No. 11).

## Aves.

*ASIO ACCIPITRINUS*, Pall. (Short-Eared Owl.)

Two bones of this bird have been found—a perfect tarsometatarsus and a broken humerus; both of these agree with the corresponding bones of the short-eared owl. They were found in the lower layer (No. 9).

*TURDUS ILIACUS*, Linn. (Redwing.)

Two ulnas and parts of two tibias, representing at least two individuals, are placed in this species. The bones of thrushes are so alike in form that, except for size, they cannot be distinguished. The present specimens are too small for a common thrush, but are of the same size as these bones in the redwing. Two specimens were found in the north-north-western lower layer (No. 11) and two in the south-south-eastern fissure (No. 10).

*ERITHACUS RUBECULA* (?) Linn. (Robin.)

A single ulna, agreeing in form and size with this bone in the robin, is, with some hesitation, referred to the same species; it was found in the north-north-western lower layer (No. 11).

## Amphibia.

## RANA TEMPORARIA, Linn. (Frog.)

About thirty bones of frogs were found, among the small bones obtained by Mr. Arnold-Bemrose by washing the cave-earth in fine sieves. Some of these are definitely referable to the above species; others, although belonging to the same genus, are not specifically determinable: sixteen of these were from the north-north-western lower layer (No. 11), three from the south-south-eastern fissure (No. 10), and the remainder from the tip-heap made by our predecessors in this work.

## BUFO VULGARIS, Laurenti. (Toad.)

Eleven bones, belonging to two individuals of large size, including three ilia, a humerus, and other limb-bones, are clearly referable to this species. Nine of the specimens were from the north-north-western lower layer (No. 11), and two from the tip-heaps.

## General Remarks on the Vertebrate Remains.

Altogether, some twenty-seven or twenty-eight species of vertebrate animals have been identified from Longcliffe, which is nearly twice as many as had been previously known from Derbyshire caves. We must remember, however, that half of these are small rodents, birds, and amphibia which have not been mentioned by previous writers. The number of larger species (sixteen) is the same as that recorded by Prof. Boyd Dawkins from Robin-Hood Cave; but there are noteworthy differences in the species. We have no evidence of the presence of man at Longcliffe, neither have we detected *Machærodus* or leopard; all the other carnivora found in Robin-Hood Cave are present also at Longcliffe, and in addition we have the badger.

Among the Ungulata there are some peculiar differences. The great Irish deer is present in both caves; but the only other deer recorded from Creswell is the reindeer: now, this is conspicuously absent from Longcliffe, and its absence is the more remarkable in that it occurs in nearly all the lists of mammals from Derbyshire caves.<sup>1</sup> On the other hand, we have at Longcliffe not only the red deer, which has been recorded from Pleasley Vale, but a great abundance of another form which we believe to be fallow-deer.

The wild boar does not seem to have been previously recorded from Derbyshire.

The rhinoceros present at Longcliffe is undoubtedly *Rh. leptorhinus*, OWEN (= *Rh. hemitæchus*, Falconer), whereas the *Rh. antiquitatis* (= *Rh. tichorhinus*), or woolly rhinoceros, is the only species hitherto recorded from Derbyshire, and it appears in nearly all the published lists.

<sup>1</sup> [Since the reading of this paper we have detected one flattened fragment of an antler, which may perhaps belong to a reindeer, from layer No. III.—*January 11th, 1905.*]

TABLE I.

	I.	II.	III.	IV.	V.	6.	7.	8.	9.	10.	11.	M.	G.	Totals.
1. <i>Felis leo</i> , Linn. (Lion.)	...	...	...	1	...	...	...	...	3	...	...	2	1	7
2. <i>Felis catus</i> , Linn. (Wild Cat.)	...	...	...	...	...	1	...	...	3	...	7	...	...	11
3. <i>Hyæna crocuta</i> , Erxl. (Spotted Hyæna.)	2	46	71	20	7	6	32	4	51	1	3	90	334	667
4. <i>Canis lupus</i> , Linn. (Wolf.)	...	2	...	1	...	...	...	1	...	...	...	...	1	5
5. <i>Vulpes alopecur.</i> Linn. (Fox.)	...	...	...	...	...	...	1	...	...	...	...	...	...	1
6. <i>Ursus horribilis</i> (?) Ord. (Grisly Bear.)	...	2	6	5	1	...	1	1	25	...	5	14	31	91
7. <i>Meles meles</i> , Schreber. (Badger.)	...	...	...	...	...	...	...	...	1	...	...	1	...	2
8. <i>Vespertilio auritus</i> (?) Linn. (Long-Eared Bat.)	...	...	...	...	...	...	...	...	...	...	1	...	...	1
9. <i>Bos</i> or <i>Bison</i> .....	29	323	459	41	6	21	266	42	16	...	...	112	540	1855
10. <i>Cervus giganteus</i> , Blumenb. (Irish Deer.)	...	...	1	...	...	...	...	...	...	...	...	...	3	4
11. <i>Cervus elaphus</i> , Linn. (Red Deer.)	...	3	6	2	...	...	4	1	1	...	...	...	21	38
12. <i>Cervus dama</i> , Linn. (Fallow-Deer.)	4	135	300	41	7	24	39	62	58	...	5	242	675	1592
13. <i>Capreolus caprea</i> , Gray (Roebuck.)	...	...	1	1	...	...	1	...	3	...	...	6	4	16
14. <i>Sus scrofa</i> , Linn. (Wild Boar.)	...	1	...	...	...	...	...	...	2	...	...	...	1	4
15. <i>Rhinoceros leptorhinus</i> , Owen .....	...	17	11	9	4	1	7	5	13	...	...	17	60	144
16. <i>Elephas antiquus</i> , Falconer .....	...	...	1	...	...	...	...	...	...	...	...	...	...	1
17. <i>Lepus cuniculus</i> , Linn. (Rabbit.)	...	2	...	...	1	...	1	...	...	39	...	...	...	43
18. <i>Lepus</i> sp. (Hare.) .....	...	...	...	...	...	...	...	...	1	...	...	1	...	2
19. <i>Microtus glareolus</i> , Schreber (Bank-Vole.)	...	...	...	...	...	...	...	...	...	...	...	...	1	4
20. <i>Microtus agrestis</i> (?) Linn. (Field-Vole.)	...	...	...	...	...	...	...	...	...	3	...	...	4	5
21. <i>Microtus amphibius</i> (?) Linn. (Water-Vole.)	...	...	...	...	...	...	...	...	...	1	...	...	1	1
22. <i>Mus sylvaticus</i> (?) Linn. (Field-Mouse.)	...	...	...	...	...	...	...	...	...	...	1	...	...	1
23. <i>Asio accipitrinus</i> , Pall. (Short-Eared Owl.)	...	...	...	...	...	...	...	...	2	...	1	...	...	2
24. <i>Turdus iliacus</i> , Linn. (Redwing.)	...	...	...	...	...	...	...	...	...	3	3	...	...	6
25. <i>Erithacus rubecula</i> (?) Linn. (Robin.)	...	...	...	...	...	...	...	...	...	...	1	...	...	1
26. <i>Rana temporaria</i> , Linn. (Frog.)	...	...	...	...	...	...	...	...	...	3	16	...	11	30
27. <i>Bufo vulgaris</i> , Laurenti. (Toad.)	...	...	...	...	...	...	...	...	...	...	9	...	2	11
Number of bones named .....	35	531	856	121	26	53	352	116	179	50	51	485	1690	4545
Number of bones undetermined .....	4	695	721	86	7	85	628	26	11	15	7	610	566	3461
Total number obtained .....	39	1226	1577	207	33	138	980	142	190	65	58	1095	2256	8006

The absence of the horse from Longcliffe is another peculiarity, for this species is likewise present in most of the Derbyshire caves.

The Longcliffe elephant, again, is peculiar, for there is no doubt as to its being *Elephas antiquus*<sup>1</sup>; while it is the mammoth (*E. primigenius*) that has been found in Robin-Hood Cave and Church Hole. Both species are known to occur in caves in other parts of England.

Very little is yet known of the small mammals and birds which existed in Derbyshire when the cave-earths were being deposited. Some of the Longcliffe deposits have been washed through sieves; but, as we have seen, the results were not encouraging. We think, however, that the few small forms found are worthy of being recorded, although the species may now be living in the district; for nearly all of them, we know from other evidence, were living in this country in Pleistocene times.

#### V. TABULATION OF THE SPECIMENS.

The total number of specimens obtained was 8006. These were all washed, treated with glue, and sorted. Of these, 2582 were in such a fragmentary condition that they were placed on one side as useless for determination. The remaining 5424 were numbered and catalogued; of these 4545 have been determined, and the remaining 879 consist of vertebræ and ribs, requiring more time for their determination than we have been able to devote to them, and of fragments which were in too broken a condition to be named. The accompanying Table I (p. 58) shows the number of each genus and species recognized from the various layers or portions of the cavern which we thought it necessary to keep distinct (see Pl. V), and the number of undetermined and broken specimens. Column M contains those specimens which we were unable to allocate to any special position worth noting, and column G those obtained before we began work.

It will be seen from the horizontal section (Pl. V, fig. 1) that the specimens obtained before we commenced the work probably belonged to one or more of the layers Nos. I–V, because they came from that part of the cavern which extended from the south-south-eastern end to a point 34 feet to the north-north-west of it and on the higher level above the line AB. There is little doubt that those from layers Nos. 6, 7, 8, & 9 belong to the same group, and were introduced through the swallow-hole. We have, therefore, grouped together the specimens from layers Nos. I–9, and kept separate those from Nos. 10 & 11 in Table II (p. 60). Of the 4545 specimens named, 4444 came from the upper series of bone-beds (Nos. I–9), 50 from the narrow joint below the south-south-eastern end of the cavern (No. 10), and 51 from the lower level above the bedded sand and clay (No. 11).

<sup>1</sup> Prof. W. Boyd Dawkins has examined the tooth, and accepts it as evidence of *Elephas antiquus*.

TABLE II.

	<i>Upper beds. I-9.</i>	<i>10.</i>	<i>11.</i>	<i>Totals.</i>
1. Lion .....	7	...	...	7
2. Cat .....	4	...	7	11
3. Hyæna .....	663	1	3	667
4. Wolf .....	5	...	...	5
5. Fox .....	1	...	...	1
6. Bear .....	86	...	5	91
7. Badger .....	2	...	...	2
8. Bat .....	...	...	1	1
9. <i>Bos</i> .....	1855	...	...	1855
10. Irish Deer .....	4	...	...	4
11. Red Deer .....	38	...	...	38
12. Fallow-Deer .....	1587	...	5	1592
13. Roebuck .....	16	...	...	16
14. Boar .....	4	...	...	4
15. Rhinoceros.....	144	...	...	144
16. <i>Elephas antiquus</i> .....	1	...	...	1
17. Rabbit .....	4	39	...	43
18. Hare .....	2	...	...	2
19. Bank-Vole .....	1	3	...	4
20. Field-Vole .....	4	1	...	5
21. Water-Vole .....	1	...	...	1
22. Field-Mouse .....	...	...	1	1
23. Owl.....	2	...	...	2
24. Redwing.....	...	3	3	6
25. Robin .....	...	...	1	1
26. Frog .....	11	3	16	30
27. Toad .....	2	...	9	11
Totals .....	4444	50	51	4545

The 39 bones of rabbit in layer No. 9 probably all belonged to one animal.

Although traces of *Hyæna* were found in each of the three groups, the forty-three coprolites of that animal were confined to the uppermost group (Nos. I-9), and five out of these were obtained in the swallow-hole.

The Pleistocene age of this assemblage of the mammalian remains we take to be abundantly proved by the presence of such forms as *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hyæna*, and lion. The only form that has not hitherto been regarded as a Pleistocene species is the fallow-deer, which, for reasons given elsewhere in this paper, we are now disposed to include in the British Pleistocene fauna (see pp. 52-53 & 61). It is probable that the clay and sand (Beds 12-15) are of more ancient origin, but in so far as they could be examined they yielded nothing to indicate their age.

As there are many duplicates of most of the species, it is hoped that a typical series will be placed in the Museums of Derby and Buxton respectively, and in the Museum of Practical Geology, Jermyn Street, London.

## VI. CONCLUSION.

There is no doubt that the cavern was eroded along a master-joint in the limestone by the action of water. This erosion must have taken place long before denudation had produced the present shape of the surface of the ground. There is little doubt that the majority of the bones were introduced through the swallow-hole; others may have fallen or been washed in at various places along the joint or roof of the cavern where it communicated with the surface of the ground.

In considering the origin and age of the bones, we may briefly examine the various alternatives:—

1. The cavern may have been a hyæna-den. The presence of a small number of gnawed bones and over forty hyæna-coprolites tend to support this view. As far as we could tell from the extent of our excavations, the only entrance to the cavern was by the swallow-hole, a more or less vertical shaft  $7\frac{1}{2}$  feet wide, the top of which was at least 12 feet above the top of the bone-deposits found in it. It is quite possible that the cave was accessible from the swallow-hole during the time when the bone-deposits were forming, and was used by hyænas until nearly filled up.

2. The mammalian remains may be merely those of animals that had fallen into the swallow-hole, but the isolated positions and fragmentary condition of the bones scarcely admit of this interpretation of the origin of the whole of the remains.

3. The deposits might have been formed at a date subsequent to Pleistocene times. That is to say, they might have been washed in from a hyæna-den or other Pleistocene deposit, and mingled with later ones. In this way the occurrence of the fallow-deer with the Pleistocene species would be accounted for. The abundant remains of what we take to be fallow-deer in nearly all parts of the bone-deposits necessitate a very careful consideration of the possibilities of these deposits being of recent origin. But the supposition that they are of recent origin would imply that the surface of land in the neighbourhood must have been sufficiently elevated above the swallow-hole to collect water to wash the remains into the cavern; and that this land has been denuded, not indeed since Pleistocene times, but since the redeposition of the bones in Roman or post-Roman times, if the fallow-deer was really first introduced into this country by the Romans. Such rapid denudation does not seem possible, and we do not think the supposition tenable.

We conclude, therefore, that the Hoe-Grange bone-deposits were of Pleistocene age; that some of the bones fell or were washed in through the swallow-hole and roof of the cavern; and that others were introduced by hyænas which used the cavern as their den.

The presence of the small deer-remains with bones of undoubted Pleistocene mammalia, under the circumstances described by us, proves, we think, that the fallow-deer, or a form which we cannot distinguish from it, existed in Pleistocene times in Britain.

[Since this paper was written, Mr. R. Lydekker has kindly called our attention to a most important memoir by Dr. Herluf Winge on the fossil mammalia of Denmark (Videnskabelige Meddelelser, 1894, p. 193), in which, at p. 263, remains of fallow-deer are described and figured from Interglacial beds in Denmark. The memoir is, unfortunately for us, written in Danish, but Mr. Lydekker has given an account of that portion of it which deals with *Cervus dama*, in his article on 'The Fallow-Deer in Denmark,' published in 'The Field' (March 5th, 1904, p. 403), where he also gives a very interesting summary of what has been written regarding the northward range in Europe of the fallow-deer in past epochs.

The presence of fallow-deer so far north as Denmark in Interglacial times, makes it extremely likely that it extended its range westward also into England. This discovery by Dr. Winge, therefore, lends considerable support to our contention that the small deer-remains found at Longcliffe belonged to fallow-deer which lived in that district in Pleistocene times.—*January 11th, 1905.*]

#### EXPLANATION OF PLATES V-VIII.

##### PLATE V.

- Fig. 1. Horizontal section of the Hoe-Grange cavern. Scale: 1 inch=15 feet.  
 2. Plan along the line AB. Upper level. }  
 3. Plan along the line CD. Lower level. } Scale: 1 inch = 15 feet.

##### PLATE VI.

- Fig. 1. View of the cavern, soon after we commenced the work, showing the wooden door at the entrance, 27 feet north-north-west of the place where the men first broke in. The rock on the left-hand side had been quarried before the cavern was discovered. (From a photograph taken by Mr. W. Walker, of Buxton.)  
 2. A more general view of the quarry, showing the position of the cavern. The line between A and B corresponds to the line AB in the horizontal section of the cavern Pl. V, fig. 1. (From a photograph taken by Mr. Arnold-Bemrose.)

##### PLATE VII.

[All the figures are of the natural size, and are reproduced from photographs.]

- Fig. 1. *Felis leo*: left ramus of the lower jaw, with milk-teeth. No. 459.  
 2. *Felis catus*: left femur, from the front. No. 4423.  
 3. *Felis catus*: right humerus, distal portion, from the front. No. 4427.  
 4. *Ursus horribilis* (?): last lower molar. No. 4533.  
 Figs. 5 & 5a. *Elephas antiquus*: half milk-molar 3, side- and end-views. No. 2289.  
 Fig. 6. *Cervus dama*: three true molars of the left side. Nos. 2050 & 2909.

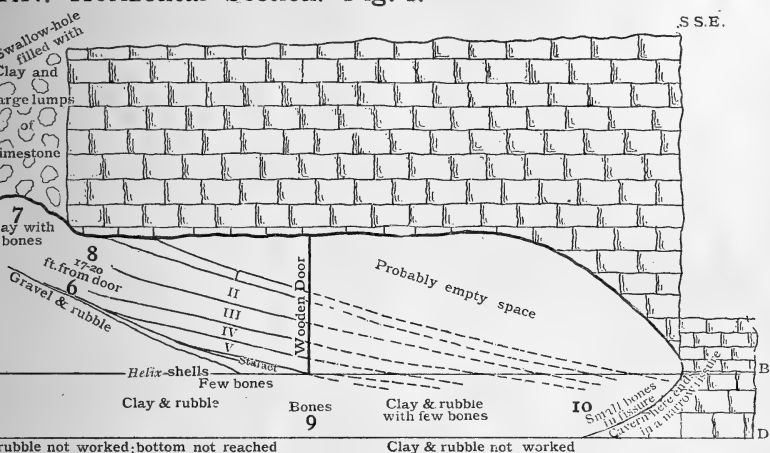
##### PLATE VIII.

[All the figures are half the natural size, and are reproduced from photographs.]

- Fig. 1. *Cervus giganteus*: metacarpal. No. 130.  
 2. *Cervus elaphus*: metacarpal. No. 278.  
 3. *Cervus dama*: metacarpal. No. 3312.  
 4. *Capreolus caprea*: metacarpal. No. 3438.  
 5. *Cervus giganteus*: astragalus. No. 142.

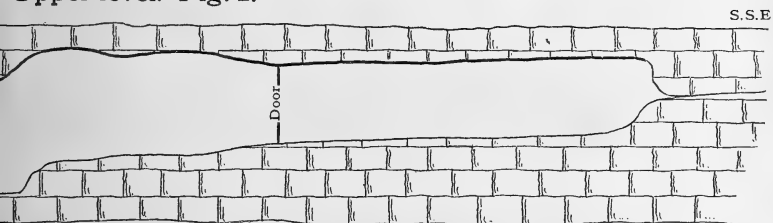


RN. Horizontal Section. Fig. 1.

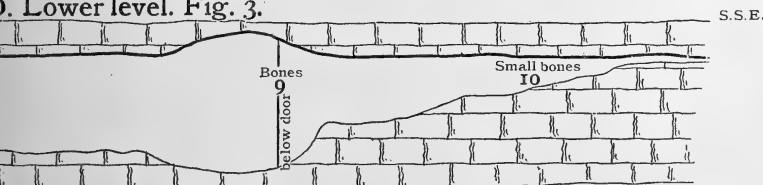


Scale:- 1 inch=15 feet

Upper level. Fig. 2.



Lower level. Fig. 3.

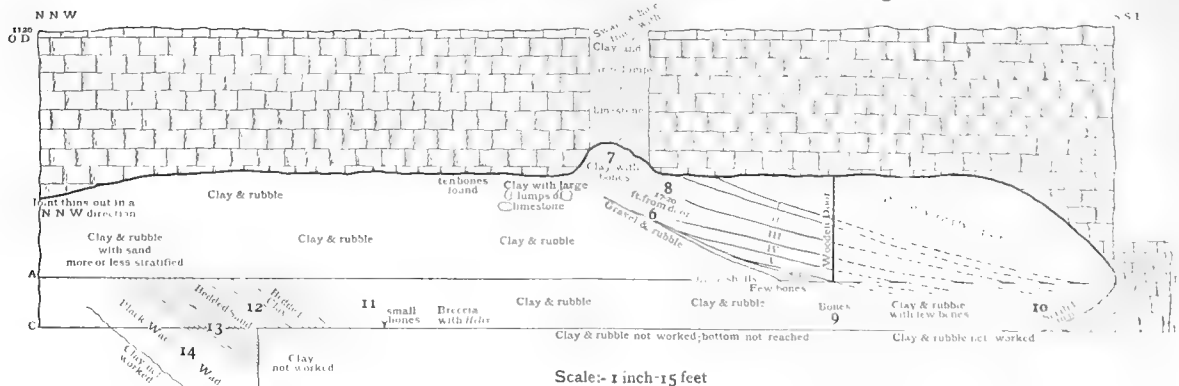


Worked in 1902, and the lower level in 1903.

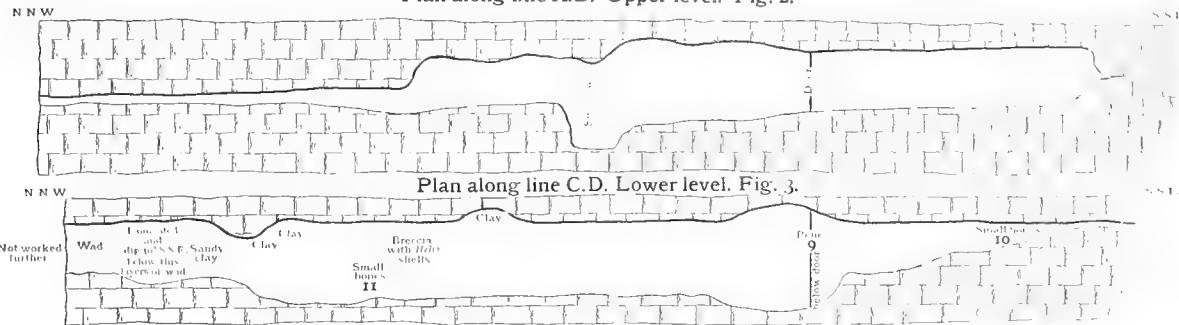
Scale:- 1 inch=15 feet.



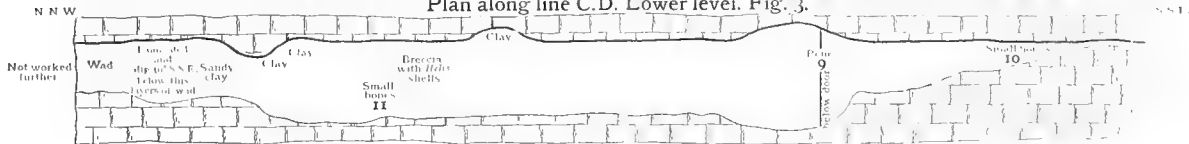
HOE-GRANGE CAVERN. Horizontal Section. Fig. 1.



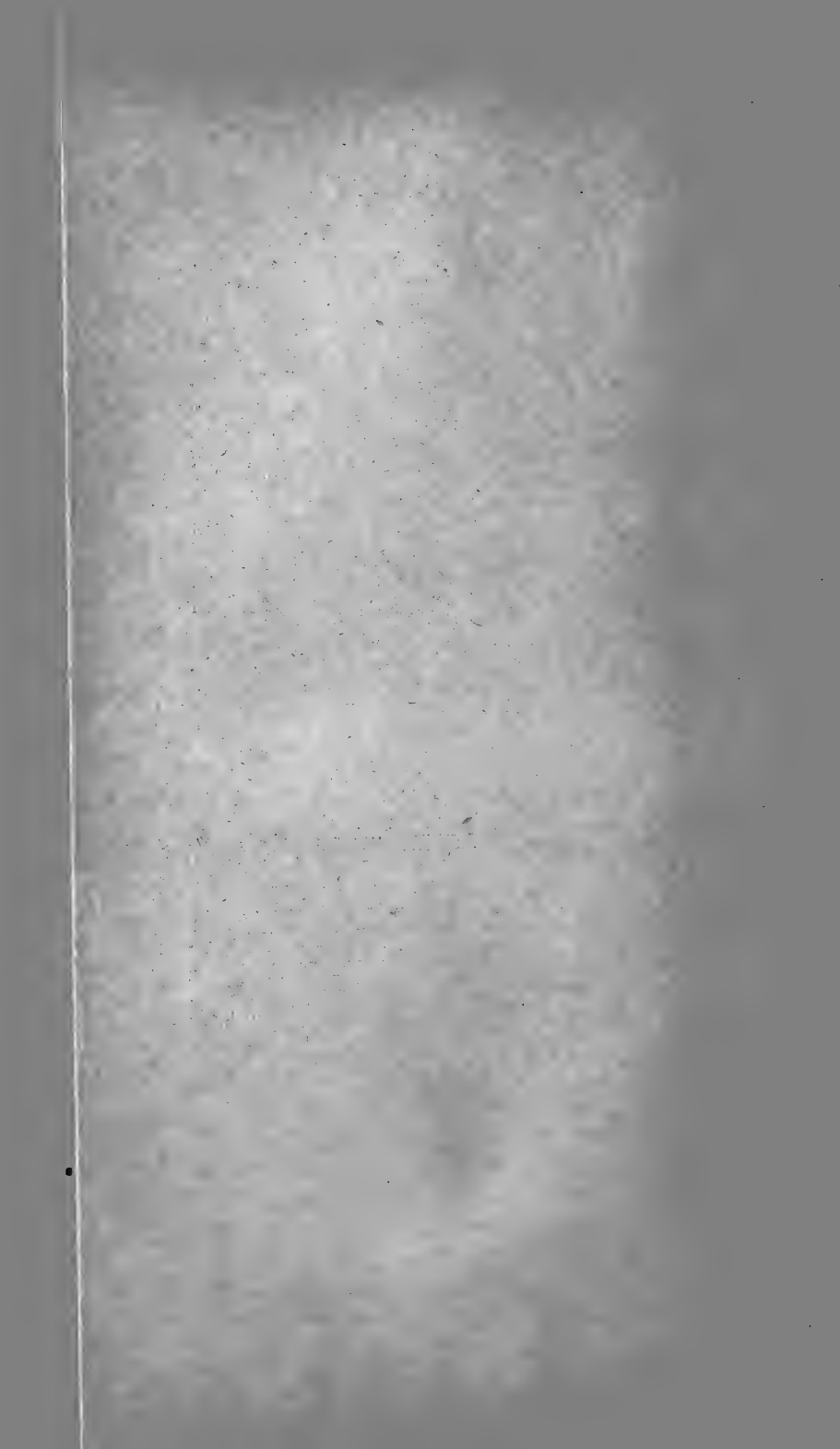
Plan along line A.B. Upper level. Fig. 2.



Plan along line C.D. Lower level. Fig. 3.



The upper level from A.B. to the roof was worked in 1902, and the lower level in 1903.



HOE GRANGE CAVERN, LOOKING N.N.W.



*W. Walker, Photo.*

FIG. 1.



*H. A. B., Photo.*

FIG. 2.



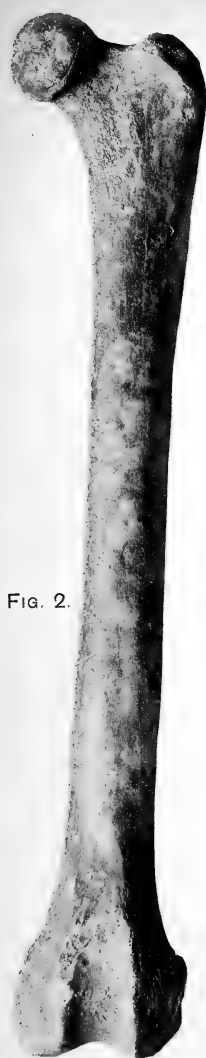


FIG. 2.

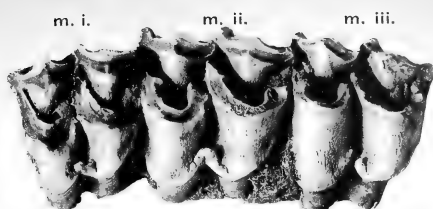


FIG. 6.



FIG. 5A.



FIG. 4.



FIG. 5.



FIG. 3.



FIG. 1.

*Bemrose, Collo.*

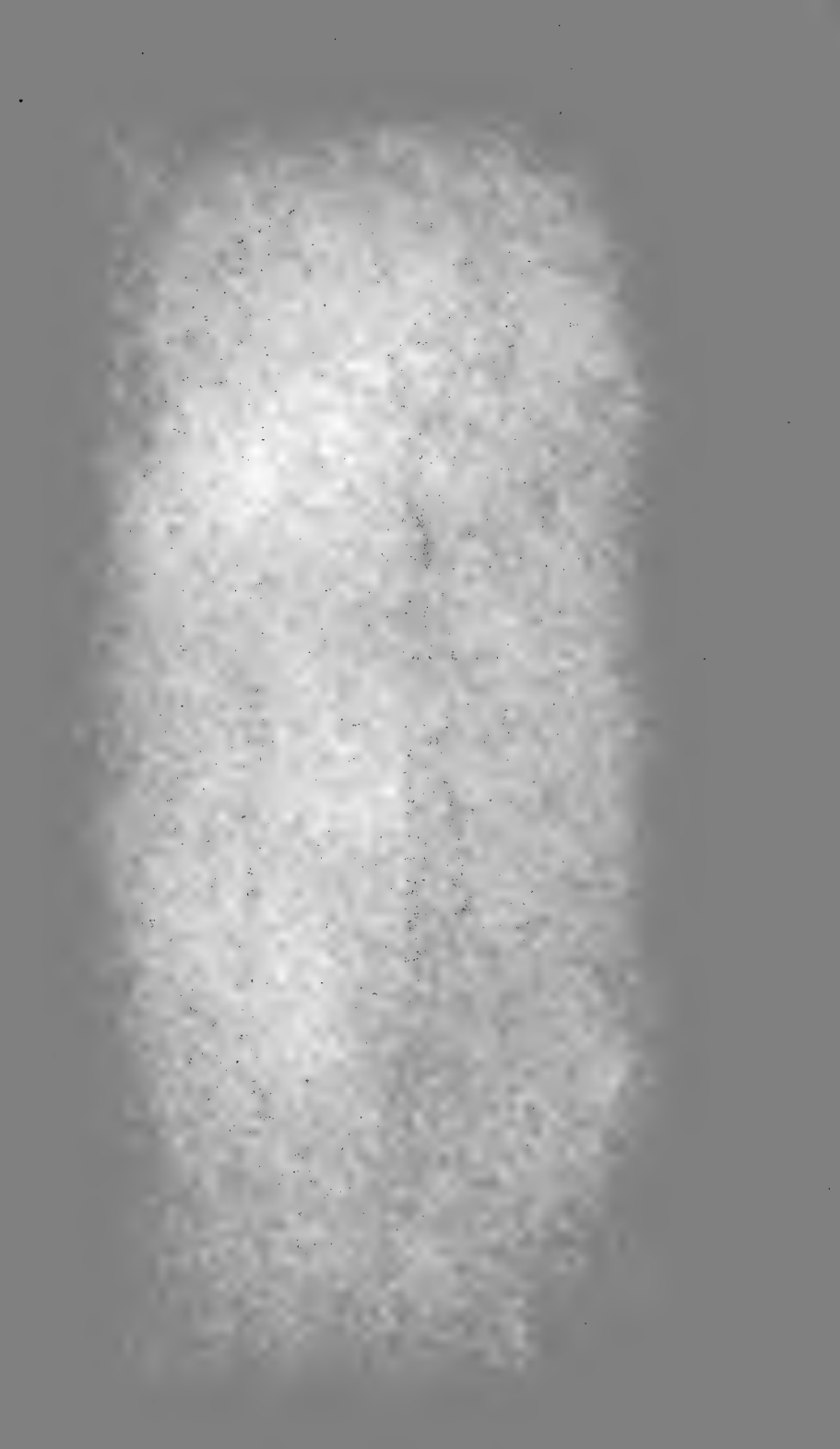






FIG. 1.



FIG. 2.



FIG. 3.

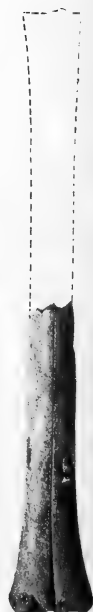


FIG. 4.

FIG. 5.

*Bemrose, Collo.*

CERVINE BONES FROM HOE GRANGE CAVERN.



## DISCUSSION.

Prof. BOYD DAWKINS welcomed the paper as one of the most important brought before any Society in this country during the last few years. The physical conditions at Longcliffe were evidently the same as at Wirksworth Cavern, and pointed to the vast denudation which had taken place since the time when the remains were introduced into those caves. The Pliocene cave at Doveholes, at a level which was now part of the watershed instead of being in the valley, also exemplified similar conditions. It would be interesting to know whether the Authors had endeavoured to measure the denudation in the case of the Longcliffe Cave, and whether they had found any decomposed grits or foreign pebbles such as occurred in many Derbyshire rock-fissures.

He doubted whether hyænas could have leaped the minimum 12 feet postulated, down the swallet, and considered that the bones had been introduced by water-action from some upper source which itself was really a hyæna-den. The occurrence of *Rhinoceros hemitæchus* and *Elephas antiquus*, together with the absence of the mammoth and the woolly rhinoceros, assimilated the deposits to those of Kirkdale Cave, a much older group of cave-deposits than was usual in this country or in France. The probable classification and relative antiquity of the Derbyshire cave-deposits would be, in chronological order: (1) Doveholes; (2) Longcliffe and the older deposits of Creswell Crags (= Kirkdale Cave); (3) upper deposits of Creswell Crags; and (4) Windy Knoll. With regard to the fallow-deer, he must express a certain amount of scepticism. Not much importance could be attached to measurements of bones or teeth, in the case of a group which varied so enormously as the Cervidæ; and there were no points which distinguished the teeth of the fallow-deer from those of the reindeer. The occurrence of the lower jaw of a lion's whelp was, on the other hand, the most important recorded from any cave in this country.

7. *The SUPERFICIAL DEPOSITS and PRE-GLACIAL VALLEYS of the NORTHUMBERLAND and DURHAM COALFIELD.* By DAVID WOOLACOTT, D.Sc., F.G.S. (Read November 23rd, 1904.)

## [PLATE IX—MAP.]

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## I. INTRODUCTION.

NEARLY the whole of the rock-surface of the Northumberland and Durham Coalfield is covered by superficial deposits of an extremely variable thickness. After I had made some study of the thickness of these deposits and the pre-Glacial contour of the north-east of County Durham, Prof. Lebour suggested to me that results of some importance might be obtained from a thorough investigation of all the borings and sinkings made in the Northern Coalfield, and the working out of this subject has occupied the greater portion of my leisure-time for the last three or four years.

Nicholas Wood & E. F. Boyd, in a paper on the 'Wash' published as long ago as 1864 (1)<sup>1</sup> first clearly showed that the deposits covering the rock-surface of this coalfield were not arranged in an irregular manner, but were found along valley-like depressions. Since then, little has been done towards the thorough elucidation of the Glacial and superficial geology of this area. Indeed, little of a detailed character could have been attempted until the publication in 1897 of the final volume of the 'Account of the Strata of Northumberland & Durham, as proved by Boring & Sinkings' (4). The six volumes published by the North of England Institute of Mining & Mechanical Engineers give details of 2,353 borings made in the Northern Coalfield, or in its immediate neighbourhood. A large number of these are useless for our present purpose, because their exact position is not known, many of them are vague and indefinite, and some fail to give the thickness of the superficial deposits. All, however, that could possibly be of any service have been carefully analysed, and

<sup>1</sup> Numerals between parentheses refer to the Bibliographical List on pp. 94-95.

their exact position accurately mapped; the depth of the surface-deposits has also been worked out, and their character has been studied.

The actual number of borings of which reliable data were available, and could therefore be used for the purpose of this inquiry, was about 600, but several hundred others gave confirmatory evidence. The remainder, although carefully gone over, did not prove to be of much service, because the facts obtained from them were always uncertain. It has, however, been found possible to obtain exact information regarding the thickness and character of the Glacial deposits; to gain a rough idea of the contour of the country before Glacial times; to form a more accurate conception of the drainage of that period; and also to work out more thoroughly the relative changes of level before, during, and after the Glacial Period.

## II. THE NATURE OF THE DEPOSITS.

The superficial deposits of the great Northern Coalfield may be roughly divided into three main parts, namely:—

- (a) The stony Boulder-Clay.
- (b) The Upper Clay, which has been generally derived from the lower stony clay, and is broadly divisible into two portions:—(1) The prismatic clay, and (2) the leafy clay.
- (c) Deposits of sand and gravel occurring below, in, or upon the Boulder-Clay.

### (a) The Stony Boulder-Clay.

The first, which is the only kind that should be called 'Boulder-Clay,' is a firm unstratified clay, full of stones, varying in weight from a few grains to several tons. It may be examined in several sections along the coast, but perhaps best at Whitley, north of Cullercoats; between North Shields and Tynemouth, on the banks of the Tyne; and at Hendon, a mile south of Sunderland. It is sometimes seen resting directly upon the surface of the solid rock, although often there is a breccia, consisting of local fragments, intervening between it and the rock-surface. Sand and gravel are also proved to occur beneath it in some of the borings. This clay is often present as one complete mass, reaching in some cases a thickness of over 100 feet with little or no change in character, except that the lower parts of it generally contain more boulders than the upper; very frequently, however, deposits of sand and leafy clay are intercalated in it. Throughout nearly the whole district its colour is brownish or bluish, but south of Castle-Eden Dene the clay becomes distinctly red and sandy. Some of the boulders occurring in it are local, more especially near the base; but a very large number foreign to the district are also found therein, being principally derived from the district lying to the north and west. Pieces of Bernician Limestone, Whin Sill, and Cheviot Porphyry are especially common; but while something has been done towards a classification of the boulders in the different super-

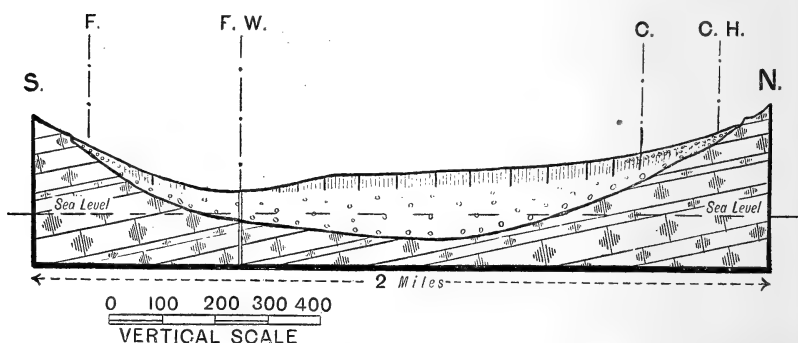
ficial deposits of the two northern counties, much detailed field-work must be undertaken before a thorough knowledge of this subject is obtained.

The rock-surface upon which this clay rests is nearly always smooth, and is in some instances striated, polished, and grooved; as are also many of the boulders contained therein, more especially those of Bernician Limestone. With one solitary exception, no remains of animal life have been found in it, portions having been washed for micro-organisms without result. It is the true Boulder-Clay, and bears no evidence of having been deposited under water, being most probably the moraine profonde of an ice-sheet. Except where the solid rock comes to the surface, the whole district is more or less covered by it; vertically, however, it is limited in height to about 1000 feet.

### (b) The Upper Clay.

(1) The prismatic clay.—Resting upon the last, or separated from it by deposits of sand, there is, in the less elevated parts of the district, a brownish clay, containing few stones; these are unstriated,

Fig. 1.—Section from Fulwell Hill to Cleadon Hills.



F.=150-foot raised beach, resting against the old sea-cliff at Fulwell.  
 F.W.=Fulwell Waterworks; C.=Cleadon Village, which is built on gravel, sand, and sandy clay.  
 C.H.=The raised beach and sea-cliff on Cleadon Hills.

and smaller and more rounded than those in the stony Boulder-Clay. This brownish clay forms, when present, a layer on the lower deposit reaching a thickness of 30 feet, and is largely used for brick-making. It has a distinct tendency to vertical prismatic jointing, and was evidently laid down under water. It is derived from the Boulder-Clay, which in some places has been washed up and re-deposited (during the extensive floods that must have occurred on the melting of the ice at the end of the Glacial Period), in other places has been washed down from the higher grounds by rain; but more generally the prismatic clay has been formed by the sea during

the production of the raised beaches which are described hereafter (p. 69). This clay can be especially well examined in the numerous brickfields around Sunderland, and along the line of the Cleadon pre-Glacial valley, having been here produced by the last-named cause. The relationship between the prismatic clay which occurs at the surface of Boldon Flats and the neighbouring district, and the raised beaches exposed on Cleadon Hill and Fulwell Hill, seems to me to be indisputable. This is shown in the section drawn between these two hills (fig. 1, p. 66), which illustrates a pre-Glacial valley, carved in Permian rocks, and filled with stony Boulder-Clay overlain by prismatic clay. Clay of this nature is also found in the north of Northumberland, there being a fine exposure of it in Birling Quarry, near Warkworth, a photograph and description of which were given by Prof. E. J. Garwood in 'The History of Northumberland' vol. v (1899) p. 12.

(2) The leafy clay that occurs in many parts of the district, as in the 'Wash' and round Newcastle, lying above the Boulder-Clay, associated with deposits of sand and sandy clay, is also probably a water-formed deposit, and may have been laid down in lakes at the end of the Glacial Period. Prof. Lebour discusses, in a 'Note on a small Boulder, found in the later Glacial Deposits in a Wash-out near Low Spenn, in the Derwent Valley' (16), the origin of this formation, and shows that it was deposited in a lake; and Mr. G. Brennan has obtained tracks of freshwater crustacea from it.

(c) Deposits of Sand and Gravel occurring below, in, or upon the Boulder-Clay.

This type of deposit is fairly widespread, and may occur in three distinct positions, each having had a separate origin. Those found below the Boulder-Clay, as in the valley of the 'Wash,' were possibly formed by pre-Glacial rivers and streams, or by the torrents that must have flowed at the commencement of the Ice-Age from the higher valleys, when they were ice-filled and the lower valleys were not so filled. The most remarkable, however, of the deposits lying in this position is exposed on the Northumberland coast, north of the mouth of the Wansbeck. It consists mainly of coarse gravel containing flints, and rests upon the solid rock-surface. Since it is overlain by Boulder-Clay, it was formed before or during the Glacial Period, and may be either a raised beach or an old river-terrace (fig. 2, p. 68); but, as the height of the land was greater before and during that period than it is now, I am inclined to the latter view. The occurrence in it of flints and other rocks foreign to the drainage-area of the pre-Glacial stream does not, however, lend support to this contention; indeed, the nature of this deposit is not yet quite understood.

The deposits of sand and sandy and leafy clay that are found embedded in the true Boulder-Clay were most probably formed by streams of water, which, resulting from the melting of the ice, would

vary in volume with change of season and climate. So far as the available evidence from the district under consideration goes, there does not seem to be anything pointing to an Interglacial Period or Periods. The deposits of sand and sandy clay found intercalated in the true Boulder-Clay are, as a rule, most irregular in position, and

Fig. 2.—*Pre-Glacial (or Glacial) gravel-deposit at Newbiggin, near the mouth of the Wansbeck.*



[From a photograph taken by Dr. J. A. Smythe in 1903. The gravel-deposit here rests upon Coal-Measures, and is overlain by Boulder-Clay.]

vary laterally in thickness. Some of the thicker deposits may represent epochs when the ice was melting more quickly than others, but whether they can be considered as in any sense 'Interglacial' is very doubtful.

While several eskers occur upon the Boulder-Clay in the north of Northumberland, outside the area of the coalfield, very few formations of this character have been noticed within the district under review. There is, however, near Grindon, about 2 miles west of Sunderland, at an elevation of 300 feet, a hillock of sand and gravel some 60 feet high, which partakes of this nature.

The mounds of sand and gravel, often designated 'Drift,' that are found resting upon the Boulder-Clay, principally in the east and south-east of County Durham, may have been produced when the enormous



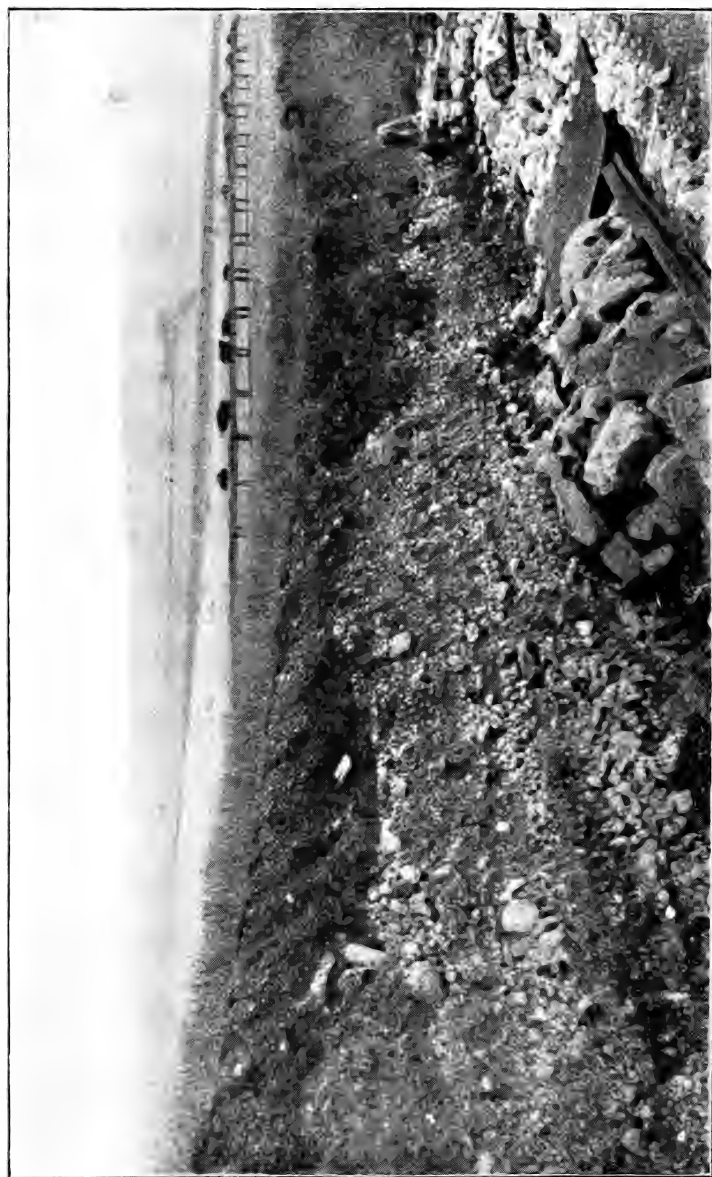
accumulations of ice were melting at the end of the Glacial Period; and also large portions of the Boulder-Clay must have been washed down from the higher ground and redeposited in the valleys, partly owing to the same cause, but also to the action of rain, etc. since that period.

Viewed broadly, there is considerable variation in the character of the superficial deposits over the whole area, and except that the Boulder-Clay is found in one or two localities to be of considerable thickness, it seems utterly impossible to correlate the deposits in different borings: this, however, was to be expected.

The discussion of the distribution of the different boulders in the clay over the great Northern Coalfield, or of the various rocks found in the diverse superficial deposits, does not come within the scope of this paper. Collecting, however, the evidence from various sources, it may be asserted that in these deposits, treated as a whole, there have been found within the area of the Coalfield, or in its immediate neighbourhood, specimens of Criffel and other granites from the South of Scotland; Borrowdale Ash and other rocks from the Lake-District; Permian and Triassic sandstone from the Eden Valley; Shap Granite (which probably does not occur very far north of the Tees Valley); Cheviot Granite and Porphyry, Whin Sill, Tuedian Sandstone, Bernician Limestone, flints, as well as specimens of the rocks that form the surface of the country itself, namely, the Coal-Measures and the Magnesian Limestone (2, 6, 15). (It is extremely doubtful, by the way, whether any true Scandinavian rocks occur north of the Tees.) I have collected specimens of most of these from time to time, but there is still room for more detailed work on this subject before a full knowledge of it can be attained.

Besides these beds, which may be considered to be more or less of true Glacial origin, there are the remains of a raised beach resting upon the solid rock and Boulder-Clay. This formation, or deposits associated with it, has been observed on Tynemouth Cliff, Cleadon, Fulwell, and Tunstall Hills, and can be traced along the coast from Seaham to Castle-Eden Dene. Richard Howse recorded a raised beach as having been exposed at Tynemouth, at an elevation of about 100 feet (2); sea-caves were discovered on Cleadon Hills, in 1878, at 140 feet above high-water mark, and the old sea-cliff with beds of gravel and sand can still be seen (5 & 6); while on Fulwell Hills (11 & 12) there is a finely-exposed beach resting in places upon a sea-worn platform of rock, and elsewhere upon Boulder-Clay, and running up against an ancient cliff which is 150 feet above sea-level (figs. 3 & 4, pp. 70 & 71). Farther south, along the coast from Seaham to Castle-Eden Dene, a hard, strongly-cemented conglomerate is traceable. At Tynemouth, Cleadon, and Fulwell many more or less fragmental portions of *Cyprina islandica* and *Littorina littorea* have been found. The most interesting point in connection with this raised beach is that it seems to decrease in height, both northward and southward, from what is probably the

Fig. 3.—*Raised beach on Fulwell Hills, from a photograph taken in 1900.*



[In the distance on the right is the Magnesian-Limestone escarpment of Cleadon Hills, while in between and stretching away to the left, is one of the minor pre-Glacial valleys, filled with superficial deposits. The view is along the line of section illustrated in fig. 1, p. 66.]

Fig. 4.—*Nearer view of the 150-foot raised beach on Fulwell Hills,  
from a photograph taken in 1900.*



exposure of maximum elevation at Cleadon and Fulwell. A gradual decrease in its height can be traced along the coast from its first occurrence south of Seaham, at an elevation of 80 feet, to Castle-Eden Dene, where it lies about 60 feet above sea-level. A raised beach, which was possibly formed at the same time, occurs at Saltburn, some 18 miles farther south on the other side of the Tees, its height there being 30 feet.

If the height of the raised beach of County Durham is original throughout its course (and it seems to be so), we have evidence of differential north-and-south movements in the uplift that produced it. The gradient is from 3 to 6 feet per mile. This aspect of the deposit has evidently a most important bearing on the conclusion enunciated by Sir Archibald Geikie in his Anniversary Address to the Geological Society, Quart. Journ. Geol. Soc. vol. lx (1904) p. civ, namely:—

‘That the changes of level, of which our islands furnish such signal illustrations, have been primarily due, not to any oscillations of the surface of the ocean, but to movements of the terrestrial crust connected with the slow cooling and contraction of our globe.’

The raised beaches cannot be traced very far inland, and this may imply that the uprise which produced them was greater near the coast; in any case, a considerable extent of country must have been covered during the time in which they were being formed; and the action of the sea on the deposits of Glacial origin in levelling their surface, and forming derived beds of gravel, sand, and sandy clay from them, has been of great moment.

The remains of submerged forests, which are exposed at irregular intervals, also occur, resting upon the other deposits at Howick, Whitburn, and West Hartlepool. I have had the opportunity of examining the former two exposures, but more especially that at Whitburn, which is unmistakably the remains of vegetation that grew *in situ*. There seems thus to be undoubted evidence of two distinct movements since the Glacial Period—the first an elevation which produced the raised beach, and the second a depression causing the submerged forests.

### III. THE DISTRIBUTION, THICKNESS, ETC. OF THE GLACIAL DEPOSITS.

The superficial deposits cover the larger portion of the great Northern Coalfield, comparatively little rock being exposed except in the higher portions of the district. In the South-East of Northumberland the thicker masses of sandstone stand out above the mantle of clay; while in Eastern Durham the Magnesian-Limestone escarpment forms a distinct feature, and its surface is not (except in the valleys) covered by any considerable thickness of superficial deposits. Some of the higher western ground of the Northern Counties was never under ice, but stood out as nunataks during the Glacial Period; and since the ice-flow mainly came down the valleys, the higher parts of Mid-Durham have no Boulder-Clay upon them. The amount of rock exposed is shown on the Drift-maps of the

Geological Survey in as accurate a manner as possible, and the maps appended to the present paper (figs. 7 & 9, pp. 82 & 85, & Pl. IX) indicate the parts of the country where the rock comes to the surface.

From some of the areas now bereft of a covering of clay, the superficial Glacial deposits have undoubtedly been removed, and the rock has been exposed along the courses of several of the post-Glacial streams, which have in many cases cut their way through rock rather than through Boulder-Clay.

The surface-deposits lie arranged in the valleys formed before the Glacial Period, and in many of them reach a considerable depth. They thus fit upon and level up the pre-Glacial inequalities of the country, being thick along the hollows that existed before the Ice-Age, and rising to a considerable height along their sides. The deepest borings through these deposits are thus all found to lie along the valleys, and, as a rule, to decrease gradually in depth as the higher ground along the flanks is reached. By mapping all the available sinkings it has been found possible to obtain the lie of the rock-surface, and a true idea of the pre-Glacial surface of the country, provided that there have been no extensive differential movements since pre-Glacial times. The following are some of the deepest borings through the superficial deposits. It will be seen that many of them go to a considerable depth below sea-level before reaching the rock-surface, and that the maximum thickness attained by these deposits, so far as the data that I have been able to collect prove, is 233 feet at Newton Hall, Framwellgate, about 2 miles north of Durham. It is, however, very probable that they reach as much as 300 feet in the valley of the 'Wash.'

LOCALITY.	VALLEY.	HEIGHT ABOVE SEA-LEVEL.	THICKNESS OF SUPERFICIAL DEPOSITS.	HEIGHT OF ROCK-SURFACE ABOVE, OR DEPTH BELOW, SEA-LEVEL.
		<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
Burdon Main .....	Tyne .....	50	191	-141
Norwood New Pit .....	'Wash' .....	16	156	-140
Blaydon .....	Tyne .....	20 (?)	145	-125
Wallsend .....	Tyne .....	72	170	-98
Percy Main .....	Tyne .....	100	193	-93
Sleekburn .....	'Sleekburn' .....	50	143	-93
Chirton .....	Tyne .....	70	145	-75
Cambois .....	'Sleekburn' .....	28	90	-62
West Chevington .....	'Sleekburn' .....	55	102	-57
Harton .....	'Cleaddon' .....	86	123	-37
Choppington .....	'Sleekburn' .....	105	116	-11
Newton Hall .....	'Wash' .....	230	233	-3
Netherton .....	.....	210 (?)	186	+24
Whalton .....	.....	300 (?)	220 (?)	+80 (?)
Bearpark .....	Brownney ...	295	202	+93

[Throughout this paper the + sign indicates that the rock-surface lies above sea-level, the - sign that it lies below.]

The variation in the character of these deposits has been already discussed, and the following typical borings show the changing nature of them clearly :—

NEWTON HALL, FRAMWELLGATE.			PERCY MAIN.		
	<i>Feet inches.</i>			<i>Feet inches.</i>	
Soil .....	1	6	Blue stony clay .....	78	6
Sandy clay .....	1	0	Sand .....	2	1
Sand, with 'scares' of coal	4	0	Blue stony clay .....	19	5
Sand, with water .....	5	0	Blue stony clay .....	48	8
Leafy clay .....	1	6	Dry stony clay .....	5	6
Sand, with water .....	1	6	Leafy clay .....	2	6
Leafy clay, 'scares' of coal	8	6	Sand .....	1	8
Gravel .....	1	4	Sand and clay .....	2	3
Leafy clay .....	6	2	Stony clay .....	2	4
Loamy sand .....	8	0	Gravel .....	1	0
Stony clay .....	2	5	Sand and water .....	1	11
Sand, with water .....	57	0	Leafy clay .....	9	6
Fine loamy clay .....	9	7	Sand .....	4	1
Sandy clay .....	0	3	Gravel .....	3	10
Sand, with water .....	10	2	Total thickness .....	183	3
Soft leafy clay .....	10	7			
Stony clay .....	6	0			
Loamy clay .....	9	0			
Loamy sand .....	10	0			
Loamy sand and leafy clay	67	1			
Stony clay .....	9	0			
Stony clay .....	3	0			
Total thickness .....	232	7			

#### IV. THE PRE-GLACIAL SURFACE OF THE COUNTRY.

A detailed study of the borings and of the exposed rock-surface enables us to form a fairly-accurate idea of the contour of the pre-Glacial surface of the country, and shows that the superficial deposits lie in a series of valleys which are (as will be more clearly proved afterwards) the courses of pre-Glacial streams. Therefore, if we had a sufficient number of sinkings, it would be possible to reconstruct the pre-Glacial drainage of the country. An attempt is made in this paper, so far as the material at command admits, to do this. All the available borings have been put in on 6-inch maps, with their height above sea-level and the depth of the superficial deposits; and then these have been transferred to 1-inch maps, which had the exposures of rock previously marked on them, and the height of the rock-surface above, or depth below, sea-level indicated. In this way the courses of the pre-Glacial valleys have been traced, and the present contour of the rock-surface roughly mapped out. It has also been found possible to compare the pre- and post-Glacial drainage, and to show that the two differ considerably one from the other.

The rock-surface in many of the valleys lies at a considerable depth beneath sea-level. The following are some of the deepest borings that prove this :—

LOCALITY.	VALLEY.	DEPTH OF ROCK-SURFACE BELOW SEA-LEVEL.
		<i>Feet.</i>
1. Burdon Main .....	Tyne .....	-141
2. Norwood New Pit .....	'Wash' .....	-140
3. Blaydon .....	Tyne .....	-125 (?)
4. Lamesley .....	'Wash' .....	-116
5. Kibblesworth .....	'Wash' .....	-108
6. Sleekburn .....	'Sleekburn' .....	- 93
7. Percy Main .....	Tyne .....	- 93
8. Chirton .....	Tyne .....	- 75
9. Cambois .....	'Sleekburn' .....	- 62

The maximum depth below sea-level at which the rock-surface is met is about 140 feet; and, judging from the number of borings, it is probable that this is about a true maximum. The height of the land is thus proved to have been in pre-Glacial times much greater than at present, and therefore the valleys in which the superficial deposits lie are the valley-track of a river-system, the streams having had their source in the Cheviots and Pennines, and the constructional shore-line lying far to the east of its present position. Indeed, at one time they may have been all tributary to a major stream running down the centre of the area now occupied by the North Sea (7). What the difference in height was we have no means of exactly judging, but that it was considerably over 140 feet higher is tolerably certain. Prof. James Geikie shows that, before the Ice-Age, Scotland stood at an elevation of from 300 to 600 feet greater than at present (3), and the borings discussed in this paper seem to point to a somewhat similar elevation for our part of the country.

The principal pre-Glacial valleys were seldom entirely obliterated, because their lower portions only were filled with Boulder-Clay; but the disappearance of some of the minor ones was complete. The 'Sleekburn Valley' (see p. 83) was entirely filled up, and could not be determined from the surface of the country; but the pre-Glacial Tyne, the 'Wash,' and the upper part of the Wear were only partly masked by the covering of Glacial deposits, and thus the solid rock still flanks the higher parts of these.

#### V. THE PRE-GLACIAL VALLEYS.

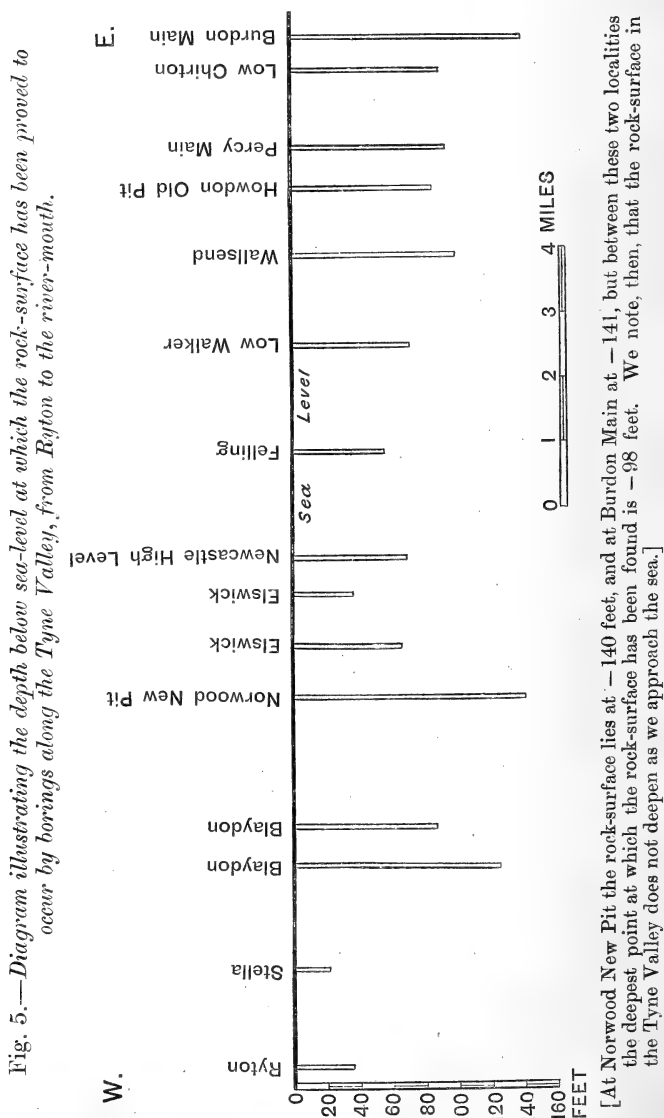
The principal pre-Glacial valleys and depressions are:—

- (a) The Tyne and its tributary valleys.
- (b) The 'Wash.'
- (c) The Upper Wear and its tributary valleys.
- (d) The 'Sleekburn Valley.'
- (e) The depression running out at Druridge Bay—the 'Druridge Valley.'

As these valleys are all fairly distinct one from the other, it will perhaps be best to give a detailed description of each, and to discuss their mutual connections as occasion arises.

## (a) The pre-Glacial Valley of the Tyne.

This is perhaps of greatest interest, as some peculiarities occur in connection with it that are not found so distinctly in any of the



others. If borings down this river are examined, they are found to prove that the rock-surface lies at a certain level beneath that of the present river, but that the slope of it is not uniformly



eastward. Thus, at Norwood New Pit, about a mile above Newcastle, and at the confluence of the 'Wash' and the Tyne, solid rock is met with at a depth of 140 feet below sea-level, and at Burdon Main, 8 miles lower down, it is 141 feet below; while, in between, all the borings prove it at a less depth, the maximum being 98 feet. This may be accounted for by supposing that none of the sinkings are in the deepest part of the pre-Glacial valley; if, however, they convey an accurate idea of the present real slope of the rock-surface, we have here (if the conception of the pre-Glacial valleys contained in this paper be correct) a definite proof of considerable differential east-and-west movements during or since Glacial times. The only way in which such an interesting point in the superficial geology of the Northern Coalfield could be settled, would be by making a line of borings across the Tyne Valley at some place between Norwood New Pit and Burdon Main, and thus obtaining the greatest depth of the rock-surface at some definite part. Until such a series has been completed, the explanation of one of the most interesting questions connected with the pre-Glacial valleys of the great Northern Coalfield, and with the geological history of the rivers of the North-East of England, must remain conjectural.

It has been already stated that the raised beach cannot be traced very far inland, and that therefore the elevation that took place when it was produced may have been a differential one, being accentuated along the coast (p. 72). If this be so, we may have here the explanation of the non-deepening of the rock-surface of the Tyne Valley as the sea is approached.

The following are the principal borings down the Tyne, from Ryton to its mouth:—

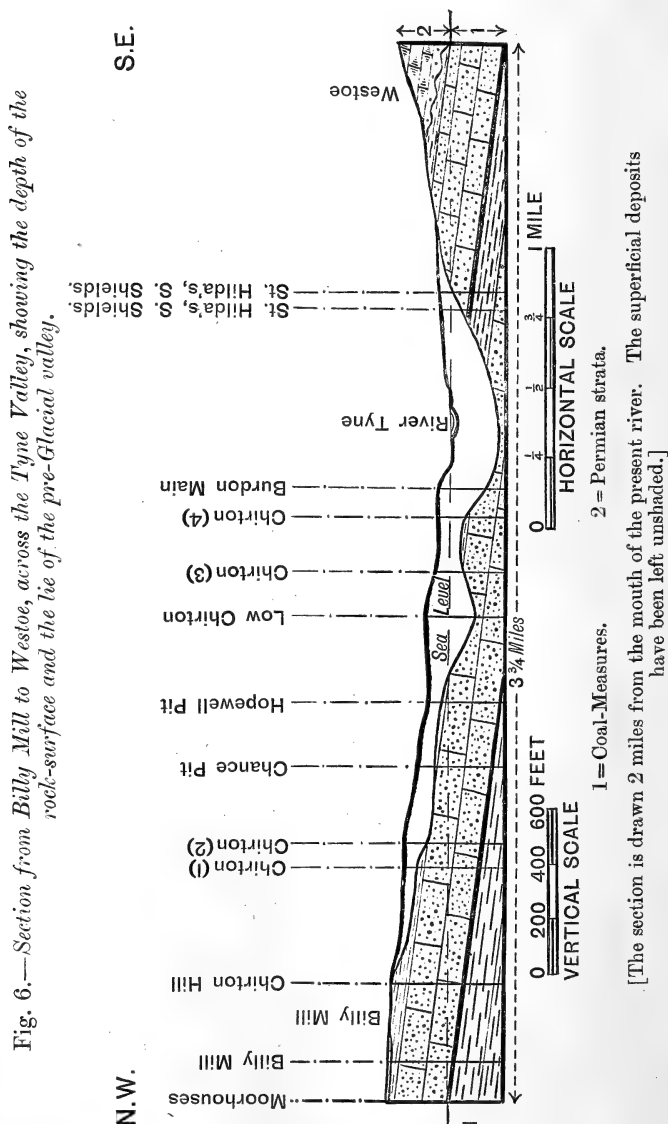
LOCALITY.	ALTITUDE.	DEPTH OF SUPERFICIAL DEPOSITS.	HEIGHT OF ROCK- SURFACE ABOVE, OR DEPTH BELOW SEA-LEVEL.
	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
Ryton .....	32	67	— 35
Stella .....	20	40	— 20
Blaydon .....	20 (?)	145	— 125 <sup>2</sup>
Norwood New Pit .....	16	156	— 140
Elswick .....	0	68	— 68 <sup>3</sup>
Newcastle High Level .....	0	70	— 70
Felling .....	75	132	— 57
Low Walker .....	60	133	— 73
Wallsend <sup>1</sup> .....	71	170	— 99
Howdon Old Pit .....	50	133	— 83
Percy Main .....	100	193	— 93
Burdon Main .....	50	191	— 141

<sup>1</sup> The altitude of the G Pit at Wallsend is given as 172 feet in the 'Borings & Sinkings,' but from the maps I suspected this to be wrong, and the manager, Mr. Phillips, kindly took the level for me. It proves to be 71·02 feet.

<sup>2</sup> Two others give similar evidence, one of —109 and another —77.

<sup>3</sup> Many borings along the Tyne at Elswick afford corroborative evidence.

The accompanying section (fig. 6), drawn across the Tyne from Billy Mill to Westoe, is especially interesting and important, because



of the numerous borings through which it passes, enabling the lie of the rock-surface to be obtained with the greatest accuracy.

The borings are :—

	ALTITUDE.	SUPER- FICIAL DEPOSITS.		ALTITUDE.	SUPER- FICIAL DEPOSITS.
	<i>Feet.</i>	<i>Feet.</i>		<i>Feet.</i>	<i>Feet.</i>
(a) Moorhouses ...	230	6	(h) Low Chirton ...	102	191
(b) Billy Mill .....	215	15	(i) Chirton (3) ...	60	111
(c) Chirton Hill ...	201	5	(j) Chirton (4) ...	62	119
(d) Chirton (1) ...	160	42	(k) Burdon Main...	50	191
(e) Chirton (2) ...	153	64	(l) St. Hilda's .....	30	53
(f) Chance Pit ...	130	60	(m) St. Hilda's,		
(g) Hopewell Pit ...	100	60	South Shields.	40	35

Although throughout the greater part of its course the post-Glacial Tyne flows at a higher level above the rock than the pre-Glacial river, there being a considerable thickness of superficial deposits between the present river and the rock-surface, yet the general trend of the two valleys is the same, the one being superimposed on the other. Especially is this so in the higher reaches, where the courses of the two waterways are almost identical; but in its lower parts, east of Newcastle, the rock is cut into at many places, as, for instance, at Felling Shore, Bill Quay, and St. Anthony's, and therefore the agreement between the old and the new valleys is not so pronounced, the course of the present river differing considerably from that of the former river in this region.

Tributary streams entered the pre-Glacial Tyne on the south side from the Allen, Devil's Water, Stanley Burn, Derwent and Cleadon valleys, and the Wear flowed into it down the 'Wash'; while from the north it received the North Tyne, and a smaller stream through Newcastle, a little to the west of the Ouseburn.

### (b) The 'Wash.'

The course, depth, and characteristics of this valley were thoroughly worked out by Nicholas Wood & E. F. Boyd in 1864 (1), and, although the genesis of such a valley was not clearly understood at that time, yet the description of it is so excellent as to require little further addition in this paper. Those writers showed that the 'Wash' extends from near Durham to the Tyne, and is filled throughout with a great thickness of Boulder-Clay and beds of sand and gravel. It is entirely carved out of the Coal-Measures, through the Hutton and other seams, and the workings in the various collieries along its sides have often been stopped by the coal abutting against the superficial deposits along this valley. At Durham the rock-surface, as proved by colliery-workings at Elvet a little to the south, lies a few feet beneath sea-level, and the maximum depth of 140 feet is found at Norwood New Pit, near the junction of the 'Wash' and the Tyne. As shown by Wood & Boyd, its slope may be uniformly northward, but there is one part lying

between Chester-le-Street and Kibblesworth along which the borings do not conclusively prove this. At the former locality the rock-surface lies at 93 feet, and near Kibblesworth at 111 feet, below sea-level. Between these there is at Brown's Buildings a boring, which was stopped in clay when a depth of 55 feet below sea-level had been reached. The greatest thickness of superficial deposits occurring in the 'Wash,' as ascertained by the borings, is 233 feet at Newton Hall, Framwellgate (about 2 miles north of Durham), but the depth may reach as much as 300 feet near that city. In the paper just referred to, the course of the 'Wash' appears to be a straight line, this being due to the manner in which it is drawn, as all the area, over which the depth of the deposits lying in it exceeds 40 feet, has been coloured; but the actual path of the deepest part of the valley, or line along which the pre-Glacial stream flowed, may be a sinuous one. The number of borings is, however, not sufficient to enable the course of the ancient river to be worked out with any great exactness.

The depth of the rock-surface and the field-evidence prove that at its upper end the 'Wash' debouches into the valley of the pre-Glacial Wear, and that it was the route taken by the drainage-waters of the west of Durham County immediately before the Glacial Period. It received a tributary stream from the east by Harraton, as it is most probable that the watershed between the 'Wash' and 'Cleadow' Valley (a tributary valley of the Tyne) had been lowered along the line taken by the present river Wear, by two streams, one flowing into the 'Wash,' and the other down the 'Cleadow' Valley into the Tyne.

The deposits filling the 'Wash' are, perhaps, the most varied of all such deposits as have been studied in the district. Associated with the blue stony Boulder-Clay are beds of sand and gravel lying below, in, or upon it; and leafy clay occurs at many parts near the surface. The origin of these various formations has been already fully discussed.

The Wear flows along the southern end of this valley, often, however, leaving the trend of it and cutting down through the superficial deposits into the rock; while the Team flows in a northerly direction over the top of them, high above the level of the rock-surface. The watershed between these two rivers is a very low and indistinct one.

The course of this valley and its connections with the pre-Glacial Wear and Tyne can be clearly followed on the map (Pl. IX).

### (c) The Upper Wear and its Tributary Valleys.

As in the case of the Tyne, the higher parts of the pre- and post-Glacial Wear valleys and their tributaries correspond. Those existing before the Glacial Period were partly filled with superficial deposits, which reach a thickness of 110 feet at Escomb and 81 near Bishop Auckland; but they were seldom entirely obliterated,

and hence the new streams that formed after that epoch agreed in direction with the old. The chief difference is that, while the pre-Glacial streams ran over the rock-surface, the present watercourses flow in the same valleys over thick deposits of Boulder-Clay and the associated formations. Thus, the upper Wear and its tributaries (the Beechburn, Bedburn, and Linburn) all flow over Boulder-Clay in well-marked valleys of pre-Glacial development, and another tributary waterway of the same age is now occupied by the Gaunless. Below Bishop Auckland the trend of the old and new valleys still continues to be very much the same as far as Durham. At Page-Bank Colliery, near which the pre-Glacial course probably passes, there is a thickness of 108 feet of superficial deposits, with the rock-surface lying at an elevation of 150 feet. The old valley then runs a little to the east of Sunderland Bridge, and afterwards by Butterby Mill, where there is a thickness of 155 feet of surface-deposits; then, stretching through by Shincliffe and Old Durham, it keeps on the east side of the city of Durham, and joins the valley of the 'Wash' already described.

The following are the principal borings down the Wear, from Bishop Auckland to Durham, and thence along the valley of the 'Wash' to Norwood New Pit:—

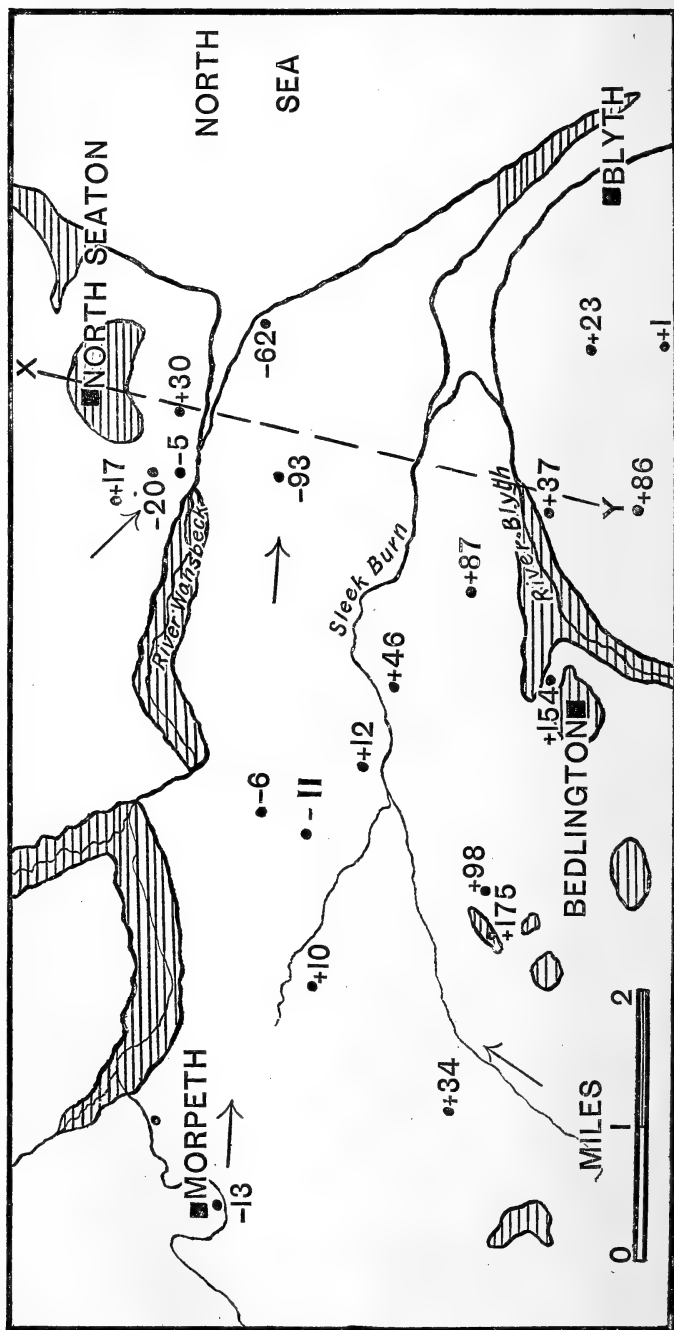
LOCALITY.	ALTITUDE.	DEPTH OF SUPERFICIAL DEPOSITS.	HEIGHT OF ROCK- SURFACE ABOVE, OR DEPTH BELOW, SEA-LEVEL.
	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
(1) Bishop Auckland .....	300	81	+219
(2) Page-Bank Colliery .....	258	108	+150
(3) Butterby Mill .....	270	155	+115
(4) Elvet Colliery .....	.....	120	0 <sup>1</sup>
(5) Newton Hall, Framwellgate...	230	233	— 3
(6) Ford Cottage, west of Cocken Hall .....	40	90	— 50
(7) Chester-le-Street .....	41	134	— 93
(8) Brown's Buildings .....	110	(?)	— 55 <sup>2</sup> or more
(9) Near Kibblesworth .....	50	161	—111
(10) Lamesley .....	50	166	—116
(11) Near High Team .....	25	158	—133
(12) Norwood New Pit .....	16	156	—140

<sup>1</sup> The rock-surface lies slightly below sea-level at this point, as proved by workings in Elvet Colliery.

<sup>2</sup> This boring was discontinued in the superficial deposits, after passing through 165 feet of them.

Between Bishop Auckland and Durham the pre-Glacial Wear received several confluent streams, the principal of which came

Fig. 7.—Map showing the relation of the post-Glacial valleys of the Wansbeck, Blyth, and Sleekburn to the pre-Glacial 'Sleekburn Valley,' the probable direction of which is indicated by the arrows.



[The shaded portions indicate those parts of the country where the solid rock comes to the surface: elsewhere it is masked by superficial deposits.]

down the valleys of the Deerness and the Browney from the west. Both of these have a considerable thickness of Boulder-Clay in them; the former 81 feet near Ushaw Moor, with the rock-surface at an elevation of 219 feet; and in the latter, quite near the river, and opposite Witton Gilbert, is a boring showing 202 feet of superficial deposits, with the rock-surface at an elevation of 93 feet. From the east two other valleys, formed by obsequent streams, joined the pre-Glacial Wear: one came down by Bowburn and Shincliffe colliery—at the former of which localities there is 120 feet of Boulder-Clay, while at the latter there is 174 feet, the rock lying at an elevation of 126; and the other ran down from the Magnesian-Limestone escarpment, passed between Pittington and West Rainton, then through Sherburn, joining the Wear Valley a little to the south of Durham.

The pre-Glacial Wear thus appears to have received all the waters from the west of Durham County, and taking up several large tributaries between Bishop Auckland and Durham City, the whole drainage was, immediately before the Glacial Period, poured down the valley of the 'Wash,' and eventually into the pre-Glacial Tyne. Not only does the evidence from the borings support this hypothesis, as already explained in the description of the 'Wash' (p. 79), but the field-evidence is entirely in favour of such a view.

The Wear below Durham leaves the trend of its pre-Glacial course, and passes over what was (before Glacial times) probably the watershed between the 'Wash' and 'Cleadow' Valleys; thus it has perforce developed an entirely-new valley since the Glacial Period. The Wear, indeed, as in the case of many other of the rivers of post-Glacial development, seems to have preferred to carve its way through rock rather than over the superficial deposits; the explanation of this most interesting phenomenon will be discussed later (p. 89). Its valley is cut deep through the Coal-Measures at Finchale Abbey, and it flows over similar strata at Hylton, while at Sunderland it has carved a well-defined valley in the Permian rocks.

The map of the pre-Glacial Wear, 'Wash,' and Tyne (Pl. IX) enables the course and connections of these valleys to be traced, and their depths can be ascertained from the numerous borings shown.

#### (d) The 'Sleekburn Valley.' (Figs. 7 & 8, pp. 82 & 84.)

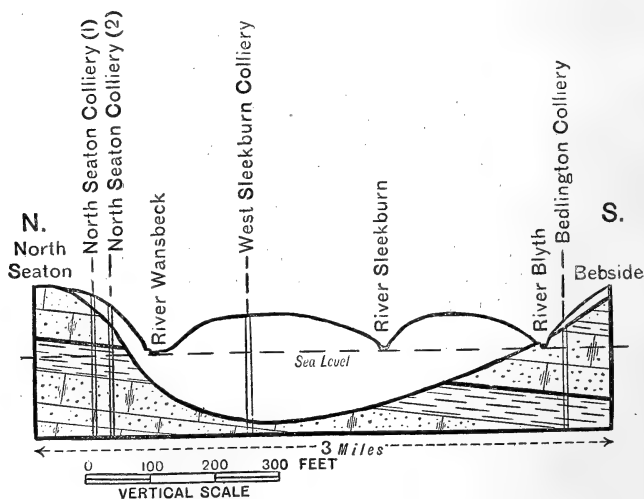
This valley is first distinctly proved by borings at Morpeth, at which place the rock-surface lies at a depth of 13 feet below sea-level. It may be traced through Choppington, Sleekburn, and Cambois, reaching a maximum depth of -93 feet at West Sleekburn Colliery. At Cambois, which is nearer the sea, the solid rock is proved at -62 feet, but this may not be the maximum at this point; or, it may be that we have here evidence of Glacial or post-Glacial movements, as in the case of the Tyne (p. 77).

The principal borings near the line of the pre-Glacial 'Sleekburn Valley' are :—

	ALTITUDE.	DEPTH OF SUPERFICIAL DEPOSITS.	HEIGHT OF ROCK- SURFACE ABOVE, OR DEPTH BELOW, SEA-LEVEL.
	<i>Feet.</i>	<i>Feet.</i>	<i>Feet.</i>
Morpeth .....	90	103	—13
Choppington (south).....	105	116	—11
Choppington (north) ..	120	126	— 6
West Sleekburn .....	50	143	—93
Cambois .....	28	90	—62

Although the connection cannot be proved by borings, the field-evidence and the exposures of rock in this part of the country show that the 'Sleekburn Valley' is probably a continuation of that of

Fig. 8.—Section across the pre-Glacial 'Sleekburn Valley,' between North Seaton and Bebside.



[The course (XY) of the section is indicated in the map (fig. 7, p. 82). The valley is carved in Coal-Measures, the lines representing which are conventional: the superficial deposits have been left unshaded.]

the Font. The valley of the latter river is pre-Glacial in origin, and now contains a considerable thickness of Boulder-Clay. On either side of the pre-Glacial 'Sleekburn' lie the Rivers Wansbeck

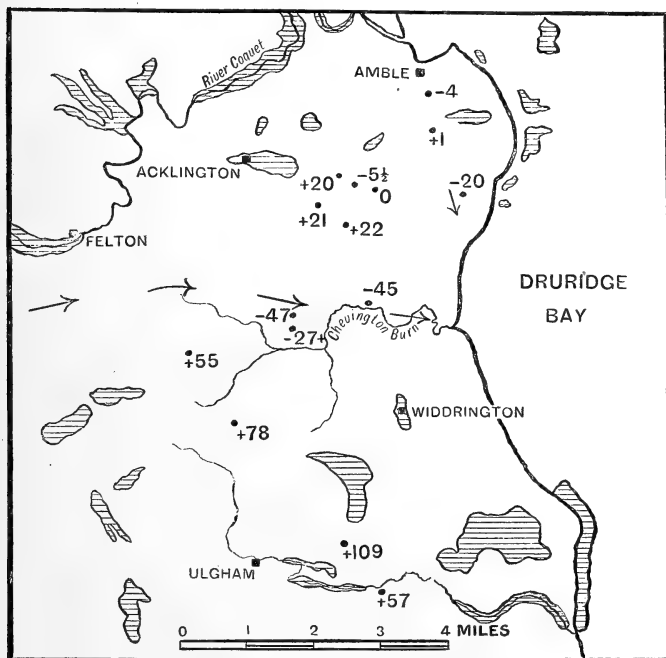


and Blyth (with its tributary the Sleekburn), all of them post-Glacial, having cut their way through rock or Boulder-Clay since the Ice-Age.

(e) The Druridge-Bay Depression. (Fig. 9.)

The Boulder-Clay is exposed along the coast for about 4 miles in Druridge Bay. This would seem to indicate the presence of

Fig. 9.—Map of the 'Druridge Valley.'



[The height of the rock-surface above, or its depth below, sea-level is indicated at the various points at which it has been ascertained by borings.

The shading indicates those parts of the country where the rock comes to the surface; the other parts are occupied by superficial deposits. The arrows indicate the probable direction of the pre-Glacial valleys.

The position of Acklington and Widdrington illustrates the fact, that a great number of the villages in Northumberland are built upon masses of sandstone which rise above the level of the surface-deposits.

The relation of the post-Glacial Coquet to the pre-Glacial valley is clearly elucidated.]

another valley of pre-Glacial origin; if, however, one does exist here, it must be broad, but not very deep. There are two borings, one about a mile, and the other 2 miles from the coast, and in a direct line with the centre of the bay, which prove the rock-surface to lie at depths respectively of 45 and more than 47 feet below

sea-level. This probably indicates the existence of a pre-Glacial valley running towards the centre of the bay, but it has not been found possible to trace the watercourse so clearly as the others already described. Other borings, both north and south of the central area, also show that the solid rock lies below sea-level, for instance, one of -27 feet on the south and another of -20 feet on the north; and all the data indicate a slope towards a medial line, thus proving a distinct pre-Glacial hollow here, with possibly one or two minor associated hollows. The existence, therefore, of a pre-Glacial valley—the 'Druridge'—at this point seems proven; but it is not so deep as either that of the 'Tyne' or 'Sleekburn,' if the borings give us a true idea of its greatest depth, which, considering their number, seems tolerably certain. There is (as proved by borings) a gradual decrease in the maximum depth of the main pre-Glacial valleys as we proceed northward from the Tyne: the pre-Glacial valley of this river being 141 feet below sea-level, that of the Sleekburn 93, and that of Druridge Bay 47. The difference amounts to 90 feet, and the distance is 20 miles. The cause of this may be that the difference in level between the pre- and the post-Glacial rock-surfaces is possibly not so considerable in the north as in the south of the great Northern Coalfield; or, as seems more likely, the streams that produced the northern valleys of the 'Sleekburn' and 'Druridge' Bay were tributary to the Tyne, and hence their valleys were not cut so deeply as the major one.

The upper part of the Coquet Valley above Rothbury had been developed before the Glacial Period, and as the valley running into Druridge Bay is in a direct line with this one, we may conclude that the Coquet prior to that period ran along the valley which we are at present considering, and entered the sea about 4 miles to the south of its present mouth. It is impossible to determine this point exactly by borings, but the exposures of rock and the lie of the Boulder-Clay prove it. The lower reaches of the Coquet, from above Brinkburn to its present mouth, are of post-Glacial development, since along this portion of its course the river cuts into solid rock at several places, and turning northward it eventually reaches the sea at Warkworth, after a meandering course over rock and Boulder-Clay.

The map of Druridge Bay and the neighbourhood, showing the lie of the rock-surface as obtained by the borings, and the exposures of rock, brings out very clearly the evidence for the existence of a pre-Glacial valley at this point (fig. 9, p. 85).

## VI. GENERAL REMARKS.

Between Blyth and Seaton Sluice is a stretch of coast-line, about 2 miles wide, formed of Boulder-Clay; and on cursory examination it might appear that there was another pre-Glacial valley here, similar to those of the 'Sleekburn' and 'Druridge.' The rock-surface certainly slopes towards a centre, and it might be argued

that the borings proving the rock at only 4 feet below sea-level did not give a true maximum; but it may be safely concluded that no important pre-Glacial valley exists at this point, there being no such indication of its higher reaches in the more elevated ground to the west, as there is in the case of all the others. Although the River Tees lies somewhat outside the area under discussion, it should be noted that the rock-surface there has been proved to lie 90 feet below the present sea-level (8). Consequently, the depth of its pre-Glacial course approaches that of the Tyne. This lends considerable confirmatory evidence to the view of the origin of the pre-Glacial valleys taken in this paper.

The borings here discussed and the evidence obtained in the field appear to make it certain, that in the age immediately preceding the Glacial Period the whole surface of the great Northern Coalfield had been denuded by a series of eastward-flowing streams, which produced the pre-Glacial valleys of which the Tyne, Wear, 'Wash,' and 'Sleekburn' are the principal remnants. The course and connections of these have been discussed; and although the present slope of the rock-surface may not be always such, as on this hypothesis it should be, the whole structure of the valleys, as well as all the field-evidence, is in support of this view of their origin. It is also what we should expect from the hypothesis regarding the development of the rivers of the East of England, put forward by Prof. W. M. Davis (9); and it is in accordance with the ideas of Mr. Jukes-Browne, regarding the evolution of the British Isles in Tertiary times (7). Further, considerable support is given to it by the work embodied in the 'Geological History of the Rivers of East Yorkshire,' by Mr. Cowper Reed (13), whose main conclusions are in agreement with those of the Yorkshire geologists (14).

If the courses of the pre-Glacial valleys are compared with those along which the present rivers flow, it will be seen that changes of considerable magnitude have taken place in the number, direction, and connections of the rivers that flow over the area under discussion.

The valleys of pre-Glacial development are broad, and their sides slope gently upward from the thalweg, thus bearing testimony to the long period during which the forces of subaërial denudation must have acted, while they were being produced. The valleys, however, which have been developed since the Glacial Period are deep and narrow, except where they correspond with those that were already in existence, and have been denuded comparatively quickly by stream-action, chiefly during and after the uplift that produced the raised beaches. Subaërial denudation has had but little effect in altering their contours. The tests for a valley developed through the rock after the Glacial Period, are that it is narrow, straight, and (in the district under consideration) deeply cut, and that it has no Boulder-Clay at its base, although the clay may occur on the top of the rock through which the valley has been

evolved. The streams flowing entirely over the superficial deposits must necessarily be of post-Glacial origin.

Besides the pre- and post-Glacial valleys of Northumberland and Durham, there are some minor valleys, sometimes totally or in part dry, and generally cutting across the watershed between two main watercourses, that are of special interest in connection with the Glacial geology of the two counties. The valleys which they join are, in all cases, of pre-Glacial development. I have seen several of these, and examined two of them in detail, namely, the Beldon Cleugh, running from the head of the Devil's Water into the Derwent Valley, and Hown's Gill, cutting across the watershed between the Derwent and the Browney; and I am in agreement with Capt. Dwerryhouse's interpretation of their origin (15), as suggested by him in this Journal. It is shown in his paper that a series of glacial lakes was formed during the Glacial Period in the pre-existing tributary valleys of the Tyne, and that the straight-cut channels, which have been developed across the watershed, are the overflow-courses of these ice-bound waters.

#### VII. DEDUCTIONS.

In the hollows occupied by the pre-Glacial valleys lie the above-described superficial deposits, and, in between, the solid rock is (as a rule) at or near the surface. In a few places, out of the trend of the major valleys or on the higher ground, the rock is below or but very little above sea-level, indicating in all probability that pre-Glacial watercourses pass through these points; a greater number of borings, however, would be necessary before all these could be accurately worked out. At many places between the main and confluent valleys, the rock rises island-like out of its mantle of Boulder-Clay and other deposits, and in the whole of the higher portions of the western districts it comes to the surface.

The valleys that had been formed before the Glacial Period were, in all probability, but very slightly altered by the ice-movement during that period. Their sides were smoothed and their contours rounded; but it seems certain that they were not appreciably deepened, nor the general trend of their direction changed. Indeed, except that they were wholly, or in part, filled with the products of the period, no changes of any very great moment were effected. That some action did take place on the rock-surface we have evidence in the 'Wash,' as (in the paper on that subject by Wood & Boyd) the upper layers of a sandstone forming the bottom of this valley are described as being 'furrowed and polished in rough and scored outlines' (1).

Prior to the period of glaciation, however, the dependence of the contour of the country on its geological structure would be much more pronounced than at present, as many of the minor features have been more or less covered up by the products of that period, and consequently in some cases obliterated; and all the bolder features have been softened. The borings and the field-work prove that the

thicker masses of sandstone, such as the 'Grindstone-Sill' round Newcastle, formed fairly-distinct escarpments in pre-Glacial times. During the Ice-Age many of these masses were planed down, *roches moutonnées* on a large scale being formed; and now, if exposed at all, their tops alone rise out of the covering of Boulder-Clay. These phenomena can be clearly observed at the present time in a quarry near Kenton, where the 'Grindstone-Sill' is worked. My attention was first drawn, by Dr. J. A. Smythe, to the rounded character of the surface of the sandstone exposed here. The escarpment facing north—which, being due to the southern dip of the rocks, would naturally exist here in pre-Glacial times—appears to have been planed down, and the whole exposure presents a rounded contour, with a slight covering of Boulder-Clay resting upon it. Another point of interest in the same connection is, that nearly all the pit-villages in the South of Northumberland (such as Killingworth, Earsdon, and Backworth) are built upon sandstone, which rises above the level of the superficial deposits.

Since the end of the Glacial Period the present rivers have perforce cut their courses in a varying platform of rock and Boulder-Clay, and, in consequence, there is considerable difference between the pre-Glacial and the post-Glacial drainage. Some of the streams flow over the top of the superficial deposits that had been laid down in the already-existing valleys; while others have left their old channels, and cut through rock or Boulder-Clay; also several entirely-new streams have been developed on the varied post-Glacial surface. It is remarkable, in this connection, how the post-Glacial rivers have often cut their way through rock rather than Boulder-Clay, and how the rivers in many cases keep to the edge of the pre-Glacial valleys, and have thus denuded the rock along their sides. The most notable case is that of the 'Sleekburn' Valley, which has had developed on either side of it the Wansbeck and the Blyth, both of which are of post-Glacial development, and cut mainly through rock. Also the Wear, in its lower reaches from Durham to near Sunderland, flows for a part of the way along the edge of a minor valley of pre-Glacial origin, running at first mainly over the Coal-Measures, and then, just before reaching the latter town, it breaks through the Magnesian-Limestone escarpment, and the rest of its course is entirely in Permian strata. Phenomena similar to these have been noted by Mr. C. Fox-Strangways (10) and Mr. Cowper Reed (13), in their descriptions of the valleys of North-East Yorkshire. The cause of this is not clear, but I would suggest that the surface of the Drift in the valleys was, immediately after its production, a convex curve following the surface of the ice that produced it, instead of (as at present) a concave one. This view of the contour of the superficial deposits gives a natural explanation of the occurrence of two streams on either side of a pre-Glacial valley, and of the way in which the rivers seem to have developed their courses through rock rather than Boulder-Clay.

Not only may the surface of the superficial deposits, when looked

at broadly, have been convexly curved, but also some time after its formation it probably lay in ridge-like mounds, as it does at present in the Vales of York and Eden, although there are few traces of such in the district under discussion. Near Gosforth, and one or two higher parts of the country, the surface lies in long ridges, but (as a rule) the whole area is perfectly flat. This levelling-out of the Drift is most noticeable near the coast-line, and was probably produced by marine action at the time of the depression marked by the raised beaches of the district.

That a great thickness of the Drift has been removed is evident; and Prof. Lebour has suggested that it is probable that the true method of obtaining a correct measurement of the total thickness of it in the valleys immediately after its production, is by finding the highest contour at which it exists along the sides of the valley and the maximum depth at which it occurs at its base. This would give us an approximation to its true thickness, although, owing to the amount that may have been removed from the flanks of the valleys, and its probable convexly-curved surface, its total dimensions may have been much greater. In the 'Wash' the Boulder-Clay creeps up to an altitude of between 400 and 600 feet, and is found at a depth below sea-level of about 140 feet; it would thus seem that, in all probability, there must have been some 600 to 700 feet of superficial deposits in this valley. The step-like river-terraces of the upper Tyne, which have been formed since the Glacial Period, and occur up to and beyond the 300-foot contour-line (thus high above the present level of the river), support this conception of the thickness of the superficial deposits, as it is manifest that they must have been produced from the Drift that once filled the pre-Glacial valley (6).

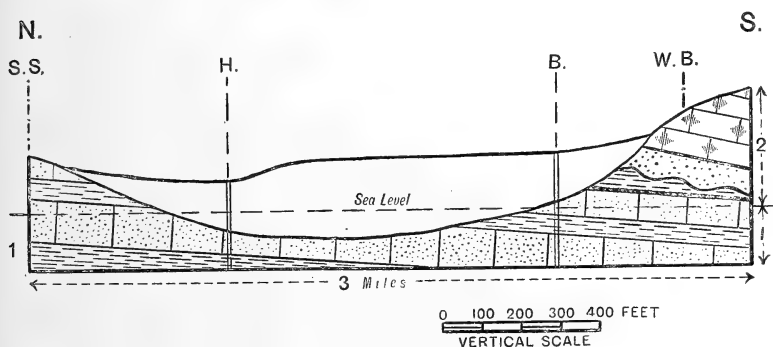
All the present courses of the rivers are of post-Glacial development; some, however, flow along the line of the pre-existing valleys. The Tyne, although deviating here and there from the course of the old valley, follows in the main the general trend of it; while the Team flows along the course of the 'Wash.' The general direction of the Derwent and the upper parts of the Wear and its tributaries is unchanged; but the lower part of the latter river, from Durham downward, has been entirely cut through Boulder-Clay and Carboniferous and Permian strata, since the end of the Glacial Period. The Blyth and the Wansbeck are also post-Glacial in origin, and have been developed mainly through rock. The present valley of the latter river affords striking evidence of the amount of denudation that has taken place since the Glacial Period: its narrow, deep, straight-cut valley having been entirely denuded in Carboniferous rocks since that time. It has also been indicated that the lower reaches of the Coquet are of similar development, and thus analogous evidence can be deduced from this river.

Along the coast from Warkworth to Sunderland several wide, sweeping, sandy bays occur; these are the points where the Boulder-Clay reaches the sea, and they mark the outlet of the pre-Glacial valleys or lower parts of the rock-surface. The principal

are the Druridge, Whitley, and Whitburn Bays, those at the end of the 'Sleekburn' and Tyne Valleys, and that south of Blyth. In between these, which are very distinct features of the coast, the sea-front is formed of rock generally capped by a thin covering of Boulder-Clay.

The escarpment of the Magnesian Limestone, which runs through County Durham from South Shields to Pierce Bridge, would in pre-Glacial times be much more pronounced than at present (fig. 10), as many of the inequalities of the country lying to the west have been masked by superficial deposits. The triangular patch of country between this line and the sea is not so thickly covered by Boulder-Clay as the surrounding district. The steep, but not very

Fig. 10.—Section across the Fulwell Valley, from Corny Hill, South Shields, to West Boldon.



S.S.=South Shields; H.=Harton Colliery; B.=Boldon Colliery; W.B.=West Boldon; 1=Coal-Measures; 2=Permian Yellow Sands, Marl-Slate, and Magnesian Limestone.

[The above section shows clearly that the Permian escarpment must have been much more pronounced in pre-Glacial times than it is now.]

high escarpment, seems to have acted as a barrier to the passage of the ice from the west and north; a similar phenomenon is, I understand from Prof. Watts, observable in the ice-sheets of the present day. In pre-Glacial times the escarpment seems to have been broken through only between Fulwell and Cleadon Hills, and since then the Wear Valley alone has been cut through it (Pl. IX).

Even before the Glacial Period, the drainage of this eastern part of the county of Durham was quite distinct from that of the west. One or two obsequent streams flowed down from the Magnesian-Limestone escarpment into the Wear between Bishop Auckland and the city of Durham, and they have their counterpart at the present day; but the main drainage was carried eastward along the dip-slope of the Permian rocks. A number of small streams flowing in that direction appear to have denuded a series of valleys in this

area, and although most of them were partly filled up by Glacial deposits, their course can be followed from the higher ground. As in the case of the main pre-Glacial valleys of the great Northern Coalfield, they have gently-sloping sides, and thus bear witness to the protracted action of the forces of subaërial denudation. Some of them are called 'Hopes,' and many are dry. Subsequent to the Glacial Period, indeed after the formation of the raised beach, several streams have developed courses, their upper parts being superimposed on the already-existing pre-Glacial valleys, and their lower cutting down through the raised beach and Boulder-Clay

Fig. 11.—*View of Hawthorn Dene, looking from the sea.*



[Hawthorn Dene is a post-Glacial valley, superimposed on a pre-Glacial one, cut in Magnesian Limestone. Upon this rests Boulder-Clay, overlain by a raised beach.]

into the Magnesian Limestone. In consequence of the uplift that produced the beach, these streams have in their lower reaches cut deep, gorge-like valleys which are now called 'Denes,' such as those of Ryhope, Hawthorn (fig. 11, above), and Castle Eden (17).

There is another point worthy of discussion in connection with the superficial deposits of the Northern Coalfield, and that is the widespread occurrence in them of flints. They have been found in the so-called 'raised beach' near Newbiggin, which is either pre-Glacial or Glacial, at the base of the Boulder-Clay near Trow Rocks, also lying above that clay near Newcastle, and in the raised beaches



of Fulwell and Cleadon Hills. They may possibly be remnants of the Upper Chalk, which was (according to some authors) deposited over a portion of the east of Durham, or they may have been, as suggested by Richard Howse, brought over from Denmark by ice (2); but it is more probable that they have been carried from an outcrop of the Cretaceous rocks in the North Sea by the ice that once occupied that area.

The entire evidence deduced from the thickness and nature of the Glacial deposits is in favour of the Glacial Period having been long and protracted; and also the proofs given of the changes in the courses of the rivers and of the post-Glacial valleys cut by them, together with that of the amount of Boulder-Clay that must have been removed to form the upper derived clay, river-terraces, and raised beaches, are all in favour of there having been an interval of considerable duration between the passing-away of the ice-sheet and the present time. Indeed, the more I work upon the Glacial deposits and post-Glacial valleys of the two counties, the more am I impressed with the length of time necessary for the production of all the phenomena.

It may not be out of place to note, that from the work done on the pre-Glacial valleys of Northumberland and Durham, it has been found possible to show that there have probably been three main cycles of river-development in the North-Eastern Counties of England. The first between the end of the Permian and that of the Cretaceous, when the point most worthy of notice is, that the uplift of the Pennines was probably accentuated in the Crossfell area, so that the South Tyne, Wear, and Tees were developed from a common centre; the second between the post-Cretaceous uplift and the beginning of the Glacial Period, when the land stood higher than at present, and the pre-Glacial valleys of the Tyne, Wear, 'Wash,' and others described in this paper, were formed, and the contour of the pre-Glacial surface produced; and the last after the Glacial Period, during which the present courses of the rivers have been developed, and the adjustment of the mountains, valleys, rivers, and streams of the counties of Northumberland and Durham evolved.

#### VIII. CONCLUSIONS.

The principal conclusions drawn from this work are:—

(i) That Northumberland and Durham stood at a higher elevation in pre-Glacial times than at present.

(ii) That a number of eastward-flowing streams had developed a series of valleys, which are now filled up with superficial deposits of very diverse character.

(iii) That in pre-Glacial times the Tyne and Tees were the major rivers, and all the other streams were tributary to them.

(iv) That the higher parts of the pre-Glacial valleys of these streams can be traced by field-work, and their lower reaches can be

followed by the borings made through the superficial deposits lying along them.

(v) That the maximum depth at which the rock-surface is met below sea-level is 141 feet, and the greatest recorded thickness of the superficial deposits is 233 feet.

(vi) That the upper post-Glacial reaches of the Tyne, Wear, and other rivers are the same as the pre-Glacial, but that in their lower parts numerous changes have taken place.

(vii) That the drainage of the Magnesian-Limestone area of the east of County Durham was in pre-Glacial times more distinct from that of the west than it is now, since the Wear Valley has been developed through it after the Glacial Period.

(viii) That the present streams flowing over this portion of the country are all post-Glacial, and have cut numerous, deep, gorge-like valleys since the uplift that produced the raised beaches.

(ix) That the elevation that caused these beaches was not uniform, and appears to have been dome-shaped, reaching a maximum on Fulwell Hills of 150 feet above the present sea-level.

(x) That the dependence of the contour of the country on its geological structure was much more pronounced in pre-Glacial times than at present.

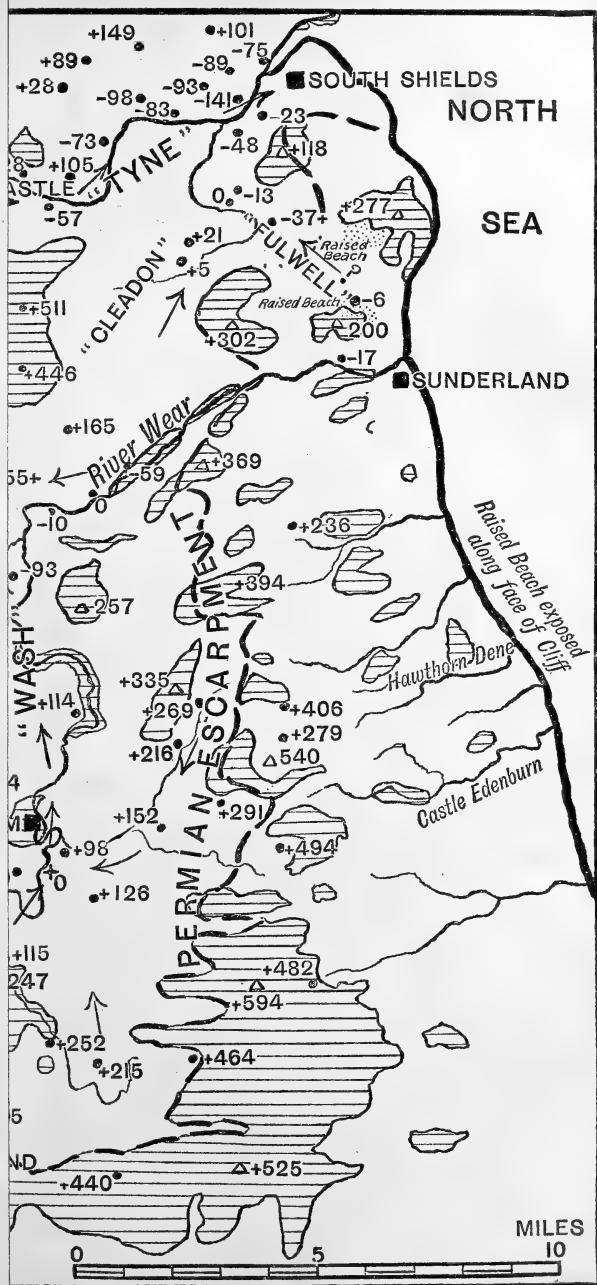
(xi) That the superficial deposits are thickest along the pre-Glacial valleys, and are not found above an altitude of 1000 feet.

(xii) That a great thickness of the original superficial deposits has been removed, and a varied series of derived formations produced.

In conclusion I wish to express my heartfelt thanks to Prof. Lebour, who inspired this work, and who has by his constant interest in it aided me in the carrying of it to a successful issue; to Prof. Watts for some helpful suggestions; to Dr. J. A. Smythe, who has been a companion in the field on numerous occasions, and has discussed many a point with me; and finally to Mr. M. Walton Brown, Secretary of the North of England Institute of Mining and Mechanical Engineers, who kindly granted me full permission to make use of such maps and data as are in the possession of that institution.

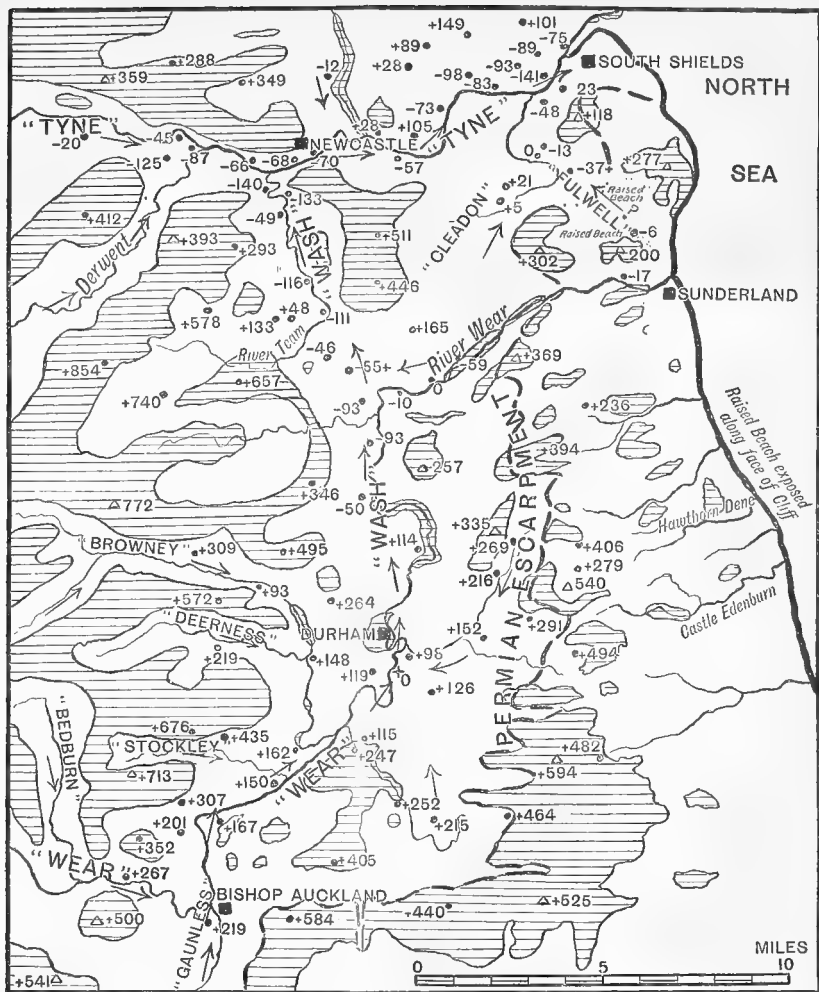
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H,' AND TYNE PRE-GLACIAL VALLEYS.





MAP OF THE WEAR, 'WASH,' AND TYNE PRE-GLACIAL VALLEYS.



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11. WOOLACOTT, D. 'On the Boulder-Clay, Raised Beaches, & Associated Phenomena of the East of Durham' Proc. Univ. of Durham Phil. Soc. vol. i, pt. iv (1899-1900) p. 247.
12. WOOLACOTT, D. 'On a Portion of a Raised Beach on the Fulwell Hills, near Sunderland' Nat. Hist. Trans. Northumberland, Durham, & Newcastle-upon-Tyne, vol. xiii (1900) p. 165.
13. COWPER REED, F. R. 'The Geological History of the Rivers of East Yorkshire 1901. [Sedgwick Prize-Essay for 1900.]
14. KENDALL, P. F. 'On a System of Glacier-Lakes in the Cleveland Hills' Quart. Journ. Geol. Soc. vol. lviii (1902) p. 503.
15. DWERRYHOUSE, A. R. 'The Glaciation of Teesdale, Weardale, & the Tyne Valley & their Tributary Valleys' Quart. Journ. Geol. Soc. vol. lviii (1902) p. 572.
16. LEBOUR, G. A. Proc. Univ. of Durham Phil. Soc. vol. ii, pt. ii (1901-1902) p. 81.
17. WOOLACOTT, D. 'Geological History of the Rivers flowing over the Coalfield of Northumberland & Durham' Proc. Univ. of Durh. Phil. Soc. vol. ii, pt. iii (1902-1903) p. 121.

### EXPLANATION OF PLATE IX.

Map of the Wear, 'Wash,' and Tyne pre-Glacial valleys, on the scale of 4 miles to the inch.

The principal borings, giving the height of the rock-surface above, or its depth below, sea-level, are shown; the parts of the country where the rock comes to the surface are shaded, the other parts (left blank) are covered by superficial deposits.

$\Delta$  = Height of the rock-surface on the higher ground, as obtained from the Ordnance-Survey maps.

The names of the principal pre-Glacial valleys are marked by inverted commas, and the arrows indicate the direction of these valleys. The map also shows the post-Glacial course of the Wear from Durham to the sea. The country lying east of the Permian escarpment slopes gently eastward, and was denuded by a series of eastward-flowing streams before Glacial times, the present streams being superimposed upon the old watercourses.

The position of the raised beach on Fulwell and Cleadon Hills is shown, and its exposure along the coast is also indicated.

### DISCUSSION.

The PRESIDENT, while not venturing to discuss the theoretical questions dealt with by the Author, said that he was glad to welcome a collection of facts of great interest, namely, the scattered records of deep borings in Drift-accumulations.

Capt. A. R. DWERRYHOUSE said that he had listened to the paper with considerable interest, and congratulated the Author upon the admirable and important work which he had accomplished. The pre-Glacial valleys which he had described were particularly interesting to the speaker, on account of their similarity to certain valleys in Yorkshire. In the southern portion of Yorkshire there were two types of pre-Glacial valleys running below sea-level, namely: the one, gorge-like valleys, such as that at Barnby Dun (near Doncaster), in which the rock-surface was reached at 170 feet

below Ordnance-datum, while borings in the immediate neighbourhood reached it at a considerably smaller depth; the other, a wide and open type, was represented by the Vale of York, the rock-floor of which some 8 or 10 miles south of York would have a breadth of several miles at the contour of 50 feet below Ordnance-datum. In calling attention to this wide pre-Glacial valley beneath the Vale of York, the speaker desired to point out that, from its form, it must be an ancient valley, and must have required a prolonged period for its excavation, during which the land stood at a higher level than at present.

The Author had mentioned that several of the pre-Glacial valleys of Northumberland were apparently shallower near their mouths than they were inland, and the same was the case in Yorkshire, there being no records of any deep channel connecting the Vale of York or the Barnby-Dun Gorge with the sea, although a large number of records existed of boreholes (both in the neighbourhood of the Humber Gap and also in the town of Hull); while farther south, the solitary cutting through the barrier formed by the Oolite-escarpment was Lincoln Gap, where the rock-floor lay at a depth of only 23 feet below sea-level.

With regard to the question of raised beaches, as pointing to a post-Glacial uplift of the coast-region, the only available evidence in Yorkshire was the pre-Glacial beach at Sewerby, which was now at sea-level, and could not therefore be correlated with the great depression of the Vale of York.

In conclusion, the speaker enquired whether the valleys which the Author had described were of the broad or narrow type.

The AUTHOR expressed his thanks for the manner in which his paper had been received. In reply to Capt. Derryhouse, he said that the pre-Glacial valleys were all broad, the Tyne being 2 miles wide at sea-level near its outlet into the North Sea. The difficulty of the slope of the rock-surface of the Tyne not being uniformly eastward, might be explained either by the borings not being made in the middle of the valley; or, more probably, by the fact that there had been differential movements since pre-Glacial times. The main conclusions drawn from the study of the pre-Glacial valleys, namely: (1) that the land stood higher in pre-Glacial times, and (2) that the valleys were produced by a series of eastward-flowing streams—seemed to the Author indisputable.



8. *On the CHEMICAL and MINERALOGICAL EVIDENCE as to the ORIGIN of the DOLOMITES of SOUTHERN TYROL.* By Prof. ERNEST WILLINGTON SKEATS, D.Sc., F.G.S. (Read December 7th, 1904.)

[PLATES X-XIV—MICROSCOPE-SECTIONS.]

### I. INTRODUCTION.

THE country of the 'Dolomites' has long been classic ground to geologists. The researches of Dolomieu<sup>1</sup> at the end of the eighteenth century, and of L. von Buch<sup>2</sup> early in the nineteenth, first aroused the interest of geologists in the district. Their attention at first was mainly directed to speculations concerning the mode of origin of the mineral, named after the French geologist, of which the mountains are so largely composed; this question, even at the present day, is far from settled. The stratigraphy of the district has always presented many points of difficulty. The earlier observers, struck by the contrast in scenery and composition between the bold, precipitous, dolomite-masses and the marls and stratified tuffs of the green pasture-lands or 'Alpen,' were at a loss to explain their mutual relations, especially as very few fossils were at first discovered in any of the deposits. In 1834, however, Graf Münster,<sup>3</sup> who had examined the strata near St. Cassian, enumerated, and (in part) described and figured 400 species of fossils from them, and subsequent observers have added largely to the number. The precise age of these deposits, which had till then been a matter of discussion, was settled by the examination of their fossil contents. It was shown not only that the beds were of Triassic age, but that, unlike the Trias of most of the European areas, they had been deposited under marine conditions. In 1845 Bronn<sup>4</sup> suggested that the St. Cassian fauna had inhabited a shallow sea where coral-banks were numerous.

The stratigraphy of the district was first systematically described by Baron Ferdinand von Richthofen,<sup>5</sup> in a brilliant paper, in which he claimed that the curious relations of the dolomitic and non-dolomitic strata could be explained if it were assumed that the masses of dolomite represented altered coral-reefs formed during a period of subsidence, while the St. Cassian marly and tufaceous deposits were laid down in the lagoons, bays, and channels of a coral-sea.

<sup>1</sup> 'Observations sur la Physique, &c.' vol. xxxix (1791) p. 3.

<sup>2</sup> 'Ueber Dolomit als Gebirgsart' Abhandl. d. k. Akad. Wissensch. Berlin, 1822-23 & 'Einige Bemerkungen über die Alpen in Baiern' *ibid.* 1828, p. 84.

<sup>3</sup> Neues Jahrb. 1834, pp. 1-15 & pls. i-ii; see also *ibid.* 1842, p. 119.

<sup>4</sup> *Ibid.* 1845, pp. 504-508.

<sup>5</sup> 'Geognostische Beschreibung der Umgegend von Predazzo, St. Cassian & der Seisser Alpe in Süd-Tyrol' Gotha, 1860, 4to.

Richthofen gave a complete account of the literature on the subject which had appeared up to 1860. His views were amplified by the work of Dr. E. von Mojsisovics and the officers of the Austrian Geological Survey, and their results were published in 1879 in the former's book.<sup>1</sup> C. W. von Gümbel,<sup>2</sup> Dr. R. Lepsius,<sup>3</sup> and others opposed the coral-reef theory of the origin of the Dolomites. In more recent years, Mrs. Ogilvie Gordon has paid much attention to the stratigraphy and the tectonics of this area, and in a series of papers<sup>4</sup> has considerably extended our knowledge of the geology of the district. She has emphasized the objections to the coral-reef hypothesis; she regards the Schlern Dolomite as a deep-water marine deposit, and seeks to explain the reef-like character of the dolomite-mountains as a result of complicated earth-movements in Tertiary times. Among the latest publications on this district is a handbook of the International Geological Congress, published in 1903, by Prof. C. Diener and Dr. G. von Arthaber, which embodies the results of the most recent work in the area of which it treats, and includes a list of the most recent papers on the subject. In May 1904, the important work 'Bau & Bild von Oesterreich' was published, and Prof. Diener was responsible for that part of it which deals with the Dolomites of Southern Tyrol.

While most geologists are now in agreement upon the general stratigraphical succession of the deposits in the Dolomites, it will be seen that antagonistic views are held as to the mode of formation of the rock-masses which now constitute the dolomite-mountains. Those who uphold the coral-reef theory point to:—

- (1) The great resemblance of the isolated dolomite-masses to upraised reefs, and the fact that corals are occasionally found preserved in them.
- (2) Their 'heteropic' character, masses of dolomite thousands of feet thick representing in age, and tailing off laterally into, marly deposits of much less thickness.
- (3) 'Reef-blocks' found on the slopes of the Dolomites, and apparently intercalated among the sedimentary deposits outside them.
- (4) The unbedded character of the rocks and their great thickness.
- (5) The fact that the rocks, like recent reefs, are often dolomitized.

<sup>1</sup> 'Die Dolomit-Riffe von Süd-Tirol & Venetien' Vienna, 1879.

<sup>2</sup> 'Das Mendel- u. Schlern-Gebirge' Sitzungsber. d. math.-phys. Classe d. k. bayerisch. Akad. d. Wissensch. vol. iii (1873) p. 14.

<sup>3</sup> 'Das Westliche Süd-Tirol' Berlin, 1878, 4to.

<sup>4</sup> 'Contributions to the Geology of the Wengen & St. Cassian Strata in Southern Tyrol' Quart. Journ. Geol. Soc. vol. xlix (1893) p. 1; 'Coral in the Dolomites of South Tyrol' Geol. Mag. 1894, pp. 1 & 49; 'The Torsion-Structure of the Dolomites' Quart. Journ. Geol. Soc. vol. lv (1899) p. 560; 'Monzoni & Upper Fassa' Geol. Mag. 1902, pp. 309 & 384; and 'The Geological Structure of Monzoni & Fassa' Trans. Edin. Geol. Soc. vol. viii (1902-1903) special part.

The opponents of the coral-reef theory state that :—

- (1) The general absence of corals in the dolomite militates against the coral-reef hypothesis. Calcareous algæ and echinoderms, but not corals, are the most common fossils.
- (2) The apparent thinning-out of the dolomite into marls and ashes is due to faulting, while the Schlern Dolomite really succeeds the St. Cassian Marls, and does not pass laterally into them.
- (3) The reef-like shape of the masses is a structural feature due also to faulting.

In view of the large amount of work done within the last 10 years in the exploration of recent coral-reefs, and the examination of the materials of which they are composed, it may serve a useful purpose to enquire if the results obtained are of such a character as may prove helpful in determining the question whether the dolomite-mountains do or do not represent old coral-reefs.

The researches of Prof. Alexander Agassiz in many parts of the Atlantic, Indian, and Pacific Oceans, the expedition to Christmas Island under Dr. C. W. Andrews,<sup>1</sup> and to the eastern group of the Fiji Islands under Mr. E. C. Andrews of Sydney University,<sup>2</sup> have added largely to our knowledge of the structure and origin of upraised coral-islands. Mr. J. Stanley Gardiner has put on record his observations at Funafuti and in the Maldives<sup>3</sup>; while the borings at Funafuti in 1896 and 1897 (under the leadership of Prof. Sollas, and afterwards of Prof. David) provided the means for the systematic examination of the materials composing a typical atoll down to a depth of 1114 feet. The Funafuti Report has recently (1904) been published by the Royal Society. The chemical examination of the cores was commenced by Dr. C. G. Cullis, and continued by Mr. J. Hart-Smith and myself, under Prof. Judd; and one of the most interesting results obtained, apart from the highly-dolomitic character of parts of the material, consisted in the discovery that the rocks forming the cores were of extraordinary purity, being practically free from insoluble residue.

During the progress of the examination of the Funafuti materials, I had an opportunity of making a chemical and microscopical examination of the collection from the upraised mass of Christmas Island, and of a selection from the collections of Prof. Agassiz, Prof. David, and Mr. E. C. Andrews from the Fiji Islands and other parts of the Pacific Ocean. The results obtained were published in June 1903, in vol. xlii of the 'Bulletin' of the Museum of Comparative Zoology at Harvard College. There I drew attention to the fact that :—

<sup>1</sup> Geogr. Journ. vol. xiii (1899) pp. 17-35 (with map) & 'Monograph of Christmas Island' Brit. Mus. (Nat. Hist.) 1900.

<sup>2</sup> Bull. Mus. Comp. Zool. vol. xxxviii (1900) pp. 1-50 & pls. i-xxxix.

<sup>3</sup> Proc. Camb. Phil. Soc. vol. ix (1898) pp. 417-503.

- (1) In those coral-islands which are remote from land-areas and volcanic rocks, the amount of insoluble residue in the limestones was negligible.
- (2) In coral-islands associated with volcanic rocks many of the limestones were found to be practically devoid of residue, but those in the proximity of the volcanic masses contained a larger quantity, amounting in some cases to over 4 per cent.

It will be noticed that in a recent coral-reef, either the whole or some part of the materials of which it is composed is devoid of insoluble residue. It is obvious that this total or partial absence of insoluble residue ought to hold good as well for a fossil coral-reef as for a recent one. I determined, therefore, to visit the Dolomites of the Tyrol, to make representative collections in this much-debated region, and to see whether a chemical and microscopical examination of the specimens would afford any evidence as to the mode of origin of the deposits. By the favour of the Council of this Society in making me the first recipient of the proceeds of the Daniel-Pidgeon Fund, I was enabled to spend a considerable part of the summer-vacation of 1903 in making typical collections of the Triassic rocks in the district. I am indebted to Prof. Judd for giving me the opportunity of analysing the material collected, and I am glad to be able to lay before the Society the results of the investigation.

The area visited is all included within the roughly-circular basin in which the typical dolomites of Southern Tyrol are best seen. The fundamental rocks, exposed only at the border of the area, consist of quartz-phyllites and schists of great antiquity, possibly of Archæan age. The earliest sediments are Permian, and succeeding these are the Triassic deposits, which cover the greater part of the basin. The Alpine movements of the mid-Tertiary age originated a series of flexures and faults, of which the majority trend roughly north-and-south and east-and-west. The shallow anticlines formed as a result of these movements have, to some extent, determined the directions of the valleys. The northern and southern valleys include those of the Eisack, Fassa, Agordo, and Ampezzo. The eastern and western valleys are not so well defined (with the exception of the Pusterthal in the north of the area), and for the most part form subsidiary depressions joining the more prominent northern and southern valleys. Over the greater part of the area, the dolomite-rocks of the Upper Trias are exposed at the surface, while the Middle and Lower Triassic deposits are only seen on the flanks of the valleys. The Permian rocks are occasionally exposed in the deepest parts of these valleys. The stratigraphical succession varies somewhat in different areas, owing to the heteropic character of the deposits. In three typical localities it is as follows:—

<i>Schlern Area, North Side.</i>	<i>Seiser Alp.</i>	<i>Tre Croci and Cortina.</i>
Dachstein Dolomite. Raibl Beds.	..... ..... <i>Pachycardium</i> -Tuffs.	Dachstein Dolomite. Raibl Beds. Schlern or St. Cassian Dolomite.
Schlern Dolomite.	St. Cassian Marls.	St. Cassian Marls and Limestones.
Augite-Porphyrite (Lower Wengen). Buchenstein Limestone. Mendola Dolomite. Dont Schiefer (Lower Muschelkalk). Campiler Schiefer. Seiser Schiefer. } Permian.	Upper Wengen Beds. Augite-Porphyrite (Lower Wengen). Buchenstein Limestone. Mendola Dolomite. Dont Schiefer.  Werfen Beds.	Wengen Sandstones. Wengen volcanic rocks.

The dolomite seen on the north-eastern flank of the Schlern Mountain, and in the Marmolata, Langkofl,<sup>1</sup> and Plattkofl massifs corresponds in age both to the Wengen and to the St. Cassian Beds. When followed eastward and northward, the dolomite is seen to rest upon St. Cassian deposits, and represents only the upper part of the dolomite from the areas just mentioned.

The Schlern Dolomite is the massive deposit that gives the characteristic appearance to many of the isolated massifs. It is this deposit which is generally claimed as being of coral-reef origin, and it is this horizon which I have particularly examined. The Mendola Dolomite has also been supposed to owe its origin to coral-reef conditions in mid-Triassic times.

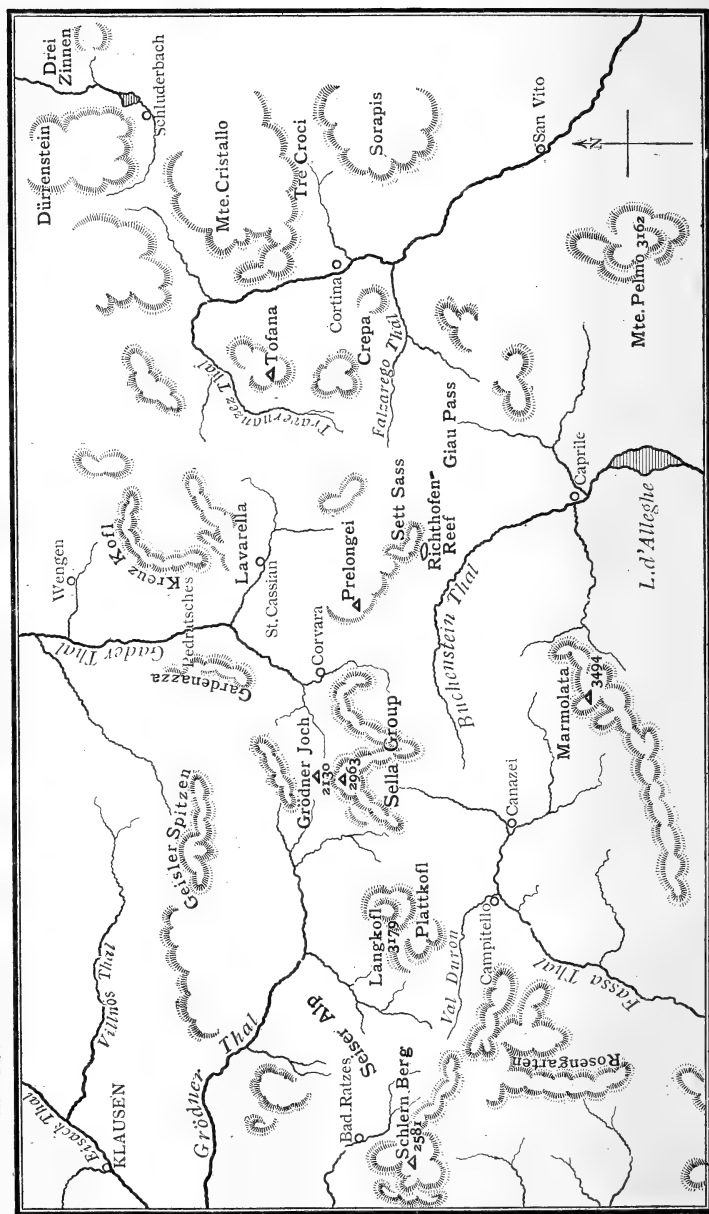
## II. THE CHEMICAL EVIDENCE.

The results of the chemical analyses of the specimens obtained from the localities visited will now be given. A few complete gravimetric analyses were made, and the results of these are recorded to two places of decimals. In the case of the majority of the specimens, only the insoluble residue and the iron and alumina, when present, were gravimetrically determined; the calcium was estimated volumetrically by a method described fully in a previous paper,<sup>2</sup> and the amount of magnesium was obtained by difference. The results of the volumetric analyses are recorded only to one

<sup>1</sup> The section of the rocks on the north-western flank of the mountain shows that the massive dolomite is underlain by bedded dolomitic limestones closely resembling the Buchenstein Limestone. Mrs. Ogilvie Gordon, however, has proved St. Cassian Beds on the eastern flanks of the mountain, and believes that the dolomite-masses overlie the St. Cassian Beds.

<sup>2</sup> Bull. Mus. Comp. Zool. vol. xlii (1903) p. 53.

# DIAGRAMMATIC SKETCH-MAP OF PART OF SOUTHERN TYROL.



Heights are expressed in metres.

decimal place. For purposes of comparison, it will be most convenient to bring together the results of analyses of rocks from the same horizon, and see how the results vary when the deposit is followed from one area to another. Since the Schlern Dolomite is the principal deposit the formation of which has been attributed to coral-reefs, it is perhaps best to consider the results of analyses from that horizon first, and subsequently to compare with them analyses of the rocks, both higher and lower, in the stratigraphical succession.

### The Schlern Dolomite.

#### Area of the Schlern.

A good section of the whole of the Triassic deposits is exposed from the summit of the mountain (8400 feet) along the marked path which is traversed during the descent to Bad Ratzes, and nearly 3000 feet of this consists of massive unbedded Schlern Dolomite. The rock, however, immediately below the plateau near the summit consists of bedded dolomite, and the first specimen analysed (No. 7) came from this upper bedded part. The succeeding specimens were taken at intervals of approximately 300 to 400 feet during the descent towards Bad Ratzes. The last specimen (No. 13) was from just above the junction of the dolomite with the augiteporphyrite:—

No.	CaCO <sub>3</sub> .	MgCO <sub>3</sub> .	Fe <sub>2</sub> O <sub>3</sub> & Al <sub>2</sub> O <sub>3</sub> .	Insoluble residue.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
7 .....	51·50	43·45	0·60	4·40
8 .....	52·70	44·80	...	2·47
9 .....	55·30	40·80	...	3·93
10 .....	54·61	43·75	1·02	0·55
11 .....	52·80	43·40	trace	3·73
13 .....	67·00	32·80	...	0·20

Three other specimens may be considered here. No. 31 was collected near the summit of the Rosszähne, the eastern prolongation of the Schlern massif, near the point where it meets the fragmental volcanic deposits of the Seiser Alp:—

No.	CaCO <sub>3</sub> .	MgCO <sub>3</sub> .	Fe <sub>2</sub> O <sub>3</sub> & Al <sub>2</sub> O <sub>3</sub> .	Insoluble residue.
	<i>Per cent.</i>	<i>Per cent.</i>		<i>Per cent.</i>
31 .....	55·3	43·8	...	0·86
β .....	56·9	41·6	trace	1·53
27 .....	60·1	39·1	...	0·73

Specimen β was from a rolled fragment, probably Schlern Dolomite, taken from the bed of the stream at Bad Ratzes. No. 27 was from a block of 'Cipit'-dolomite from the Seiser Alp.

In 1875 Prof. C. Doelter & Prof. R. Høernes wrote a paper on the composition of the Dolomites of the Tyrol, and published the results of a number of analyses.<sup>1</sup> They recorded two analyses from the dolomite of the Schlern Mountain: the first one from a

<sup>1</sup> Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) pp. 293-332.

specimen 80 feet below the summit, the second from a specimen 1000 feet above Schlernbach. The first specimen contained 1.33 per cent. of iron-oxide and residue, while .71 of insoluble residue was obtained from the second.

### The Langkofl.

In this area also the dolomite probably corresponds in age both to the Wengen and to the St. Cassian deposits, since on the north-eastern side of the mountain it is seen to follow conformably the representative of the Buchenstein Beds.

The first two specimens (Nos. 96 & 95) were blocks fallen from the upper part of the mountain. Nos. 94, 93, & 92 were taken in descending order, *in situ* from the eastern side of the mountain facing the Sella massif. No. 92 was taken only a foot or so above the junction with the bedded Buchenstein Limestone.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insoluble residue. Per cent.	
* 96 .....	54.7	45.3	0.02	* Not in place.
* 95 .....	54.7	45.3	0.013	
94 .....	54.7	41.3	4.00	
93 .....	68.9	29.0	2.13	
92 .....	56.1	43.9	trace	

It will be noticed that three of the specimens are practically devoid of insoluble residue. Nos. 94 & 93, containing residue in considerable quantity, are specimens of a reddish dolomite-conglomerate, which lines the almost-vertical eastern face of the mountain. This material, both in its appearance and in its mode of occurrence, closely resembles a reef-talus. It will be seen that two of the specimens have the composition of a true dolomite.

### The Marmolata.

The four specimens collected were obtained from the northern flank of the mountain, near its base, and during the ascent to the Fedaja Pass. No. 32 was from an immense fallen block, at the lower end of the Fedaja Valley. Nos. 33, 34, & 35 were from rocks higher up the valley, the two last-mentioned specimens being taken from the southern shores of the Fedaja See. The dolomite exhibits a fairly-steep northerly dip, and has at its base Buchenstein Beds. Hence, the lower parts of the mass from which the specimens were collected are probably of Wengen age. Augite-porphry lava of that age abuts against the northern slopes of the massif, and No. 35, containing 0.6 per cent. of insoluble residue, was taken from near the junction with the volcanic rock.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insoluble residue. Per cent.	
35 .....	97.3	2.1	.6	* Not in place.
34 .....	97.0	3.0	...	
33 .....	95.8	4.2	...	
* 32 .....	86.7	13.0	.26	



Profs. Døelter & Hørnes<sup>1</sup> recorded two analyses of rocks from the Marmolata, near the Fedaja See, in which the insoluble residues amounted to .06 and .03 per cent. respectively. The analyses indicate that the massif, as a whole, is very free from insoluble residue, and is for the most part not dolomitized.

### The Sella.

The specimens were collected in sequence from the northern slopes of the Sella Mountain, on descending from the Gröden Pass towards Colfusco. No. 101 was taken from a block fallen from the upper part of the mountain; No. 99 from near the junction with the subjacent St. Cassian Limestone; while No. 98 represents a specimen of the St. Cassian Limestone, analysed for comparison with the dolomitized rock above it.

No.	CaCO <sub>3</sub> . <i>Per cent.</i>	MgCO <sub>3</sub> . <i>Per cent.</i>	Insoluble residue. <i>Per cent.</i>	
* 101 .....	55.7	44.3	...	* Not in place.
102 .....	79.3	20.2	0.46	
100 .....	80.5	18.2	1.26	
99 .....	81.7	17.4	0.93	
98 .....	88.2	8.2	3.53	

Taking the results in ascending order, we find that the amount of insoluble residue, which is high in the St. Cassian Limestone, falls on ascending the Dolomite Series, the uppermost specimen being devoid of residue.

On the other hand, the percentage of magnesium-carbonate rises from 8 in the St. Cassian Limestone to 44 in the dolomite of No. 101, the intermediate specimens being dolomitic limestones. Profs. Døelter & Hørnes<sup>2</sup> recorded an analysis of a dolomite from Schloss Wolkenstein, west of the Gröden Pass, which contained .11 per cent. of insoluble residue.

### The St. Cassian District.

#### Lavarella.

No.	CaCO <sub>3</sub> . <i>Per cent.</i>	MgCO <sub>3</sub> . <i>Per cent.</i>	Insol. res. <i>Per cent.</i>	
82 ...	54.7	45.3	.033	The three specimens were collected, in descending order, from the dolomite-mass of Lavarella, east of St. Cassian. It will be seen that insoluble residue is practically absent, and that the specimens are dolomites of theoretical composition. An analysis of a St. Cassian Limestone (No. 76), from the slopes below Lavarella, shows considerable residue and over 10 per cent. of magnesium-carbonate.
81 ...	54.7	45.3	.013	
83 ...	55.5	44.5	.013	
76 ...	84.1	10.2	5.73	

<sup>1</sup> Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) p. 319.

<sup>2</sup> *Ibid.* p. 320.

## Sett Sass.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insoluble residue. Per cent.	
* 112 .....	54.8	45.2	...	* Not in place.
107 .....	54.6	44.2	1.20	
108 .....	54.6	44.1	1.26	

Three specimens were collected from the northern end of Sett Sass. No. 112 was taken from a block fallen from the upper part of the mass; No. 107 from the upper, and No. 108 from the lower part of the mass at the junction with the St. Cassian Limestone below.

## The Richthofen Reef.

Residue is absent from Nos. 112 & 110, but present in fair quantity in Nos. 107 & 108.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insol. res. Per cent.	
110 ...	54.7	45.3	...	The rocks are all dolomites of theoretical composition. The Richthofen Reef is a wedge-shaped mass, apparently interbedded with the St. Cassian Limestone which occurs below Sett Sass.

## St. Cassian Limestones from Sett Sass.

Two analyses of St. Cassian Limestones from this district are included for comparison with the dolomites. No.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Fe <sub>2</sub> O <sub>3</sub> . Per cent.	Insol. res. Per cent.	
109...	90.7	6.0	3.33	trace	109 was taken from the rock lying between the base of the dolomite of
111...	78.1	11.8	3.73	6.40	

Sett Sass and the Richthofen Reef; No. 111 from just below the Richthofen Reef. It will be seen that the limestones are only slightly dolomitized, that they are distinctly ferruginous, and that, while No. 109 is free from insoluble residue, No. 111 contains over 6 per cent.

## The Cortina District.

## Col Crepa.

Specimens Nos. 49 to 51 were collected, in descending order, from the western side, and Nos. 62 & 64 from the northern side of Col Crepa near Cortina. This

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insol. res. Per cent.	
49 ...	60.1	39.9	...	hill consists of Schlern Dolomite
50 ...	60.0	40.0	...	
51 ...	56.7	42.8	.46	faulted on all sides against St. Cassian and Wengen Beds.
62 ...	59.9	40.1	.013	
64 ...	62.0	38.0	.02	It will be noticed that the rocks, while highly dolomitic, are not theoretical dolomites, and that (with the exception of No. 51) they are practically free from insoluble residue.

The following seven analyses are from scattered localities within a few miles of Cortina :—

### Giau Pass.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insol. res. Per cent.	No. 37 was from the Giau Pass, about 6 miles south-west of Cortina. The specimen was not in place, but the altitude of over 7000 feet at which it was found renders it probable that the rock belongs to the Schlern-Dolomite horizon.
37...	91.5	7.4	1.13	

### Hexenfels.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insol. res. Per cent.	Nos. 56 & 59 were collected about 7 or 8 miles west of Cortina, No. 59 being from just below the junction with the Raibl Beds.
56 ...	54.33	45.36	0.05	

### Travernanzez Valley.

59 ...	60.0	39.5	0.46
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### Sorapis.

55 ...	55.5	43.3	1.20	No. 55 was collected from the western flanks of Mount Sorapis, about 4 miles south-east of Cortina.
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### Monte Cristallo.

46 ...	58.5	38.3	3.20	No. 46 was from the south side of Monte Cristallo, just below the junction with the Raibl Beds.
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### Tre Croci.

40 ...	57.2	42.5	0.26	Nos. 40 & 41 were taken from an exposure of St. Cassian Dolomite, east of Tre Croci.
41 ...	54.6	43.9	1.53	

It will be seen that Nos. 40, 56, & 59 contain only a small amount of residue, while the remaining specimens have over 1 per cent. With the exception of No. 37, the rocks are highly dolomitic.

### The Dürrenstein Area.

No. 66 came from the summit of the Dürrenstein (9300 feet).

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insol. res. Per cent.	Nos. 67, 68, & 69 were taken during the descent to the Seeland Alp. No. 72 came from the eastern base of the Strudelkopf, the southern continuation of the Dürrenstein massif. Nos. 68 & 69 contain a relatively-high amount of residue, the remaining three specimens practically none, while all are dolomites of well nigh theoretical composition.
66 ...	55.2	44.8	...	
67 ...	54.5	45.5	0.026	
68 ...	55.2	43.9	1.93	
69 ...	54.4	44.3	1.26	
72 ...	54.2	45.7	...	

## The Drei Zinnen Area.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Insol. res.	The three specimens were collected during the descent of the upper part of the Rienz Thal, on the western flanks of the Drei Zinnen. No. 71 A was not in place. All three specimens represent dolomites devoid of insoluble residue.
71A...	54.7	45.3	...	
70 ...	54.3	45.7	...	
71 ...	55.0	45.0	...	

It now remains to record, for comparison with the Schlern Dolomite, analyses from rocks below and above it.

## Analyses from Beds below the Schlern Dolomite.

## Wengen Limestone.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Fe <sub>2</sub> O <sub>3</sub> . Per cent.	Insol. res. Per cent.	The Wengen Beds of the Seiser Alp include some limestones, and an analysis of one of them (No. 22) shows that a very high percentage of insoluble residue and less than 5 per cent. of magnesium-carbonate are present.
22 ...	64.9	4.7	4.62	20.84	

## Buchenstein Beds.

Immediately below the dolomite of the Schlern, Langkofl, and Marmolata comes a nodular siliceous limestone—the Buchenstein Limestone. Two analyses were made from this horizon. No. 18 is from the base of the Schlern, above Bad Ratzes; No. 88 from the Gader Gorge, in the Valley of Abtei, about 1 mile north of St. Leonhard. Both analyses show a high percentage of insoluble residue and a small amount of magnesium-carbonate.

## Mendola Dolomite.

The Mendola Dolomite occurs only in certain districts, and represents a local modification of the Upper Muschelkalk. No. 19 is from the Schlern massif, below the Buchenstein Limestone and above Bad Ratzes. No. 26 is from the Pufels Schlucht, north of the Seiser Alp, and leading into the Gröden Valley. The insoluble residue in each case approaches 1 per cent., and the magnesium-carbonate falls short of that in a theoretical dolomite by 3 or 4 per cent.

No.	CaCO <sub>3</sub> . Per cent.	MgCO <sub>3</sub> . Per cent.	Residue. Per cent.
19 ...	58.2	40.9	.93
26 ...	57.4	41.9	.73

## Lower Muschelkalk.

Only one analysis was made from this horizon, the specimen (No. 86) being taken from the Gader Gorge in the Valley of Abtei. It will be noticed that the rock contains comparatively-little magnesium-carbonate, but much insoluble residue.

No.	CaCO <sub>3</sub> . <i>Per cent.</i>	MgCO <sub>3</sub> . <i>Per cent.</i>	Residue. <i>Per cent.</i>
86 .....	56·6	12·2	31·20

## Analyses from Beds above the Schlern Dolomite.

Succeeding the Schlern Dolomite is a deposit of variable character, marls containing gypsum, coral-limestones, or dolomitic rocks. They are known as the Raibl Beds, are usually iron-stained, and are never of any great thickness. Following these comes a great thickness of limestones or dolomites, usually of a bedded character, known as the Dachstein Beds. These form the uppermost beds of the Trias, corresponding in age to the Rhætic deposits, and they are in some places more than 3000 feet thick.

## Dachstein Dolomite.

No.	CaCO <sub>3</sub> . <i>Per cent.</i>	MgCO <sub>3</sub> . <i>Per cent.</i>	Insol. res. <i>Per cent.</i>
1 ...	56·5	43·4	·07
42 ...	60·4	39·6	trace.
61 ...	58·7	41·3	·013
104 ...	54·8	45·2	trace.

No. 1 is from the summit of the Schlern.

No. 42 from the southern flanks of Monte Cristallo, below Tre Croci.

No. 61 from the Val de Travernanzez, west of Monte Tofana.

No. 104 from the western end of Sett Sass.

In each case the specimens were collected from the base of the deposit, immediately above the junction with the red Raibl Beds. It will be noticed that the base of the deposit is a dolomite of very great purity and approaching the theoretical composition.

The Dachstein Beds are not always so devoid of insoluble residue, for Profs. Døelter & Hørnes<sup>1</sup> record two analyses of dolomites containing respectively ·67 and ·98 per cent. of residue, the first from the summit of Pordoi (south of Monte Sella), the second from the Fanis Alp.

## Raibl Beds.

No. 4 is from the Schlern plateau, just below Burgstall; while

No.	CaCO <sub>3</sub> . <i>Per cent.</i>	MgCO <sub>3</sub> . <i>Per cent.</i>	Insol. res. <i>Per cent.</i>
4 ...	52·8	43·6	3·53+Fe <sub>2</sub> O <sub>3</sub>
73 ...	68·1	28·2	3·66

No. 73 is from below the military post on the western flanks of the Dürrenstein, above the Seeland Alp. In each case the amount of in-

soluble residue present is considerable.

<sup>1</sup> Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) pp. 322, 323.

## III. DISCUSSION OF THE CHEMICAL RESULTS.

In considering the results of the foregoing analyses, two points of especial interest arise :—

- (1) The mode of formation of masses of dolomite.
- (2) The significance of the presence or absence of insoluble residue in a limestone.

The first point will be dealt with in considering the mineralogical evidence.

Sir John Murray's work in connection with the *Challenger* Expedition added largely to our knowledge of the nature, composition, and mode of formation of the deposits which are now being laid down on the sea-bottom. It was found that in all the deep-sea deposits insoluble residue was present in amounts which rarely, if ever, fell below 1 per cent., often reached 3 to 5 per cent., and occasionally rose to as much as 20 per cent. It is generally agreed that deep-sea deposits rarely attain any great thickness, since they accumulate with extreme slowness. The presence in deep waters of carbon-dioxide under pressure determines the solution of much of the calcareous parts of the tests of the minute organisms which form the deposit, and as solution proceeds the proportion of insoluble to calcareous material becomes greater. From external sources other products, such as finely-divided volcanic material and cosmic dust, also contribute to the amount of insoluble matter in deep-sea formations. When a deposit composed of the skeletons of calcareous organisms is being laid down near a coast formed of non-calcareous rocks, finely-divided detrital matter intermingles with the calcareous skeletons, so that the resulting limestone is rendered impure.

Some thin fringing coral-reefs may be of this character. I have recorded an analysis of such a reef-rock from Singatoka (Viti Levu).<sup>1</sup> Shallow-water impure limestones may also be formed by the intermingling, not of detrital matter, but of finely-divided volcanic débris with the purely-calcareous material. Recent coral-reefs growing in the vicinity of volcanoes ejecting ashes often have such insoluble matter included within them. Mango, an upraised coral-island in the Lau group of the Fijis, provides an example of an impure limestone of this character.<sup>2</sup>

A chemically-pure limestone must have been deposited under some such conditions as the following :—

1. The material must have accumulated rapidly. If it had been slowly deposited, solution of the calcareous parts of the organisms and the raining-down of volcanic material and cosmic dust would raise the percentage of insoluble residue.

2. The deposit must have been laid down in shallow water, since only under these conditions do calcareous organisms exist in sufficient abundance to give rise to thick and rapidly-formed deposits.

<sup>1</sup> Bull. Mus. Comp. Zool. vol. xlii (1903) p. 79.

<sup>2</sup> *Ibid.* pp. 71-73.

3. In general, such a limestone would not be deposited near a non-calcareous shore-line, nor in the vicinity of volcanoes ejecting ashes.

These conditions are fulfilled, so far as I am aware, by only one kind of deposit forming at the present day, namely in coral-reefs, especially in those remote from great land-masses. I have already drawn attention<sup>1</sup> to the high degree of purity of the limestones from many of the upraised coral-islands of the Indian and Pacific Oceans; while, in the Report on the Atoll of Funafuti,<sup>2</sup> the chemical results demonstrate that this typical atoll is composed entirely of limestone and dolomite almost wholly free from insoluble residue.

In considering the origins of limestones of geological antiquity, we may say in general that:—

1. A chemically-pure limestone has been formed under 'coral-reef' conditions.

2. A limestone which, throughout its bulk, does not contain less than 1 per cent. of insoluble residue, has been formed either in deep water or as a detrital deposit, or has been laid down within the range of the finer ejectamenta from a volcano.

3. A limestone which in parts is pure, and in parts contains residue, has probably been formed under 'coral-reef' conditions, but from time to time the area of deposition has been invaded either by detrital or by volcanic material.

We are now in a position to interpret the results of the analyses, so far as the amount of residue which they contain may throw light upon the mode of origin of the deposits.

## Wengen and St. Cassian Dolomites.

### Area of the Schlern.

From a consideration of the amount of residue alone, one might be led to conclude that the rocks in this area represent deep-sea deposits, since most of the analyses show well over 1 per cent. of residue. One specimen, however, contains only .2 per cent. If the deposit were of deep-water origin, we should expect it to be thin and well-bedded. We have to deal, however, with a mass of unbedded dolomite approaching 3000 feet in thickness, laid down contemporaneously with a much thinner series of shallow-water limestones, marls, and tuffs, formed over the area of what is now the Seiser Alp, to the north of the Schlern massif. The probability is, then, that this mass of dolomite represents a limestone rapidly formed in a subsiding area, and impregnated with very finely-divided volcanic material from submarine volcanoes lying to the north.

This view is supported by the fact that, interbedded with the Schlern Dolomite a few hundred feet above its base, there occurs a deposit, a few feet thick, in which the volcanic fragments are bigger

<sup>1</sup> Bull. Mus. Comp. Zool. vol. xlii (1903) pp. 103–104.

<sup>2</sup> Roy. Soc. 1904, pp. 368 *et seqq.*

and so numerous that the rock assumes the character of a submarine calcareous tuff. In this connection it may be mentioned that a partial analysis of the insoluble residue from specimen No. 7, near the Schlern plateau (p. 103), gave 64·26 per cent. of silica and 23·23 per cent. of ferric oxide and alumina. Slight reactions for calcium, magnesium, and sodium were obtained, and a stronger indication of the presence of potassium. A short distance below the summit of the Schlern, on the southern and western sides, a later outpouring of the augite-porphry lava is interbedded with the Schlern Dolomite.

#### Area of the Langkofl.

The two specimens which contain much residue come from material lining the steep eastern slope of the mountain, and possibly represent a reef-talus. Analyses from the solid mass of the mountain show only a trace of residue. This, in conjunction with the great thickness of the deposit, supports the view that it was a coral-limestone formed during subsidence.

#### Area of the Marmolata.

Of the specimens collected *in situ*, two contain no residue, and two analysed by Profs. Dœlter & Hoernes<sup>1</sup> are similarly free from insoluble matter. The only specimen containing an appreciable quantity (·6 per cent.) was collected from near the junction of the dolomite with the contemporaneous lava poured out to the north of the area. The facts again favour the view of the formation of the deposit as a coral-limestone during a period of subsidence.

The three areas just considered were subjected to similar conditions of deposition, during a movement of subsidence commencing not later than the Wengen period (in the Schlern area it commenced in the Upper Muschelkalk period), and continued until a 'negative' movement which set in at the commencement of the Raibl period.

In the remaining areas to be considered, the formation of the deposit, which now consists mainly of dolomite, did not commence until after the deposition of the Lower St. Cassian Marls and Limestones. It is not surprising to find, therefore, that the dolomite is much thinner than in the areas already considered; at Tre Croci, near Cortina, for instance, the thickness is reduced to about 300 feet.

#### St. Cassian Dolomites.

##### Area of the Sella.

An examination of the results of analyses from the dolomite of the Sella shows a progressive decrease in the amount of residue present, from below upwards. It would seem that to the north and east of the Schlern, Langkofl, and Marmolata massifs we

<sup>1</sup> Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) p. 319.



have an area which, after the cessation of volcanic activity in St. Cassian times, consisted probably of shallow-water depressions and lagoons in which the subsequent deposit was laid down. At first, no doubt, the reefs were contaminated by detrital fragments from the volcanic deposits in the neighbourhood, and this is borne out by a chemical examination of the deposits. As subsidence and deposition continued, the volcanic detritus was gradually sealed up, and the subsequently-deposited material became freer from residue, as is seen from an inspection of the results of the analyses from higher horizons. It may or may not be significant that the later-formed limestones have been more completely dolomitized than the older deposits in this area.

#### The St. Cassian District.

The analyses would appear to indicate that the Lavarella mass is free from residue, and is probably of coral-origin. At Sett Sass, south of St. Cassian, the first-formed deposit, like that of the Sella, was mixed with insoluble material, and the origin of the two deposits appears to be the same. The Richthofen Reef, a lenticular mass in the earthy St. Cassian Limestone, below the dolomite of Sett Sass, appears to have been formed during a quiescent period, in clear water devoid of sediment.

#### The Cortina District.

The faulted dolomite-mass of Col Crepa and Belvedere contains little or no residue, and appears to have been a coral-limestone formed rapidly in clear water. The analysis from the Hexenfels rock near Cortina also indicates a dolomite of great purity. The remaining analyses, from scattered localities in the neighbourhood, show generally more residue, and the rocks were possibly deposited in a coastal area supplying detrital material to the deposits.

#### The Dürrenstein Area.

The dolomite in this northern part of the district is much thicker than near Cortina. Rapid deposition under reef-conditions in a subsiding area would appear to have set in at the commencement of the period (an analysis from the base of the Strudelkopf shows no residue), and to have continued until the close, with intermittent deposits into which detrital matter was introduced (Nos. 68 & 69).

#### The Drei Zinnen Area.

The specimens from the Rienz Valley at the base of the Drei Zinnen are dolomites of great purity, in all probability deposited under reef-conditions.

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We have now to consider the composition of the beds below and above the Schlern and St. Cassian Dolomites.

In areas outside the Schlern, the Langkofl, and the Marmolata, Q. J. G. S. No. 241.

the dolomite rests upon limestones and marls, named after St. Cassian, where they are well seen. They are for the most part earthy limestones, oolitic in places, and probably of detrital origin, since for the most part they contain a rather large amount of residue. Locally, as at Sett Sass, they become very rich in beautifully-preserved branching corals, and an analysis of one of these shows that, while it is very ferruginous, it is almost devoid of insoluble residue. On the Seiser Alp, intercalated with the volcanic tuffs of St. Cassian age, lenticular masses and blocks of limestone or dolomite, which are known as 'Cipit'-limestone, occur. An analysis of a specimen taken from one of these blocks shows it to be highly dolomitic and to contain surprisingly little residue (73 per cent.), considering its intimate association with the St. Cassian tuffs. As these blocks not infrequently contain reef-forming corals, there seems little doubt that they represent scattered reef-like patches of corals, which established themselves during a temporary abatement of volcanic activity in the areas in which they are found.

An analysis of one of the earthy Wengen limestones found on the northern slopes of the Seiser Alp, shows a great admixture of insoluble matter, probably volcanic in origin. Proximity to land is indicated by the local occurrence (in the Gader Valley, for instance) of plant-remains in the Wengen deposits.

The Buchenstein Limestones, while not so earthy as those of Wengen age, are shown in two cases to contain between 7 and 9 per cent. of residue, and are probably of detrital origin, as contemporaneous volcanic rocks of Buchenstein age appear to be rare.

The Mendola Dolomite contains over 40 per cent. of magnesium-carbonate, and rather less than 1 per cent. of residue in the two examples analysed. It presents, therefore, a considerable resemblance to some of the Schlern Dolomites, and may have been formed as a reef to which some detrital material had access.

The only remaining limestones from the Older Triassic rocks are of Lower-Muschelkalk age. These are very impure, an analysis of one from the Gader Gorge showing over 30 per cent. of residue. They are, in all probability, of detrital origin. Possibly the older crystalline rocks of the neighbourhood were not entirely submerged, and these would serve to account for the presence of so much insoluble matter.

After the formation of the Schlern Dolomite the area of deposition was restricted, in consequence of 'negative movements'; some of the area was raised above sea-level, and the succeeding Raibl Beds were laid down in lagoons, salt-water lakes, etc., for we find that in different places the Raibl deposits vary greatly in character. Reddish marls, sandstones, gypsum, dolomite, and patches of coral are all represented. Possibly some of the magnesium in these beds is to be attributed to direct deposition from concentrated salt-water, and the erosion and solution of some of the Schlern Dolomite, as well as the presence of minute volcanic fragments, would suffice to account for the 3 or 4 per cent. of insoluble residue found in

some of the dolomites of Raibl age. At the close of the Raibl period a further depression of the district became general, and thoroughly-marine conditions supervened. The first-formed Dachstein deposits were probably of the nature of coral-reefs, since the base of the dolomite is very free from residue. The bedded character of most of the deposit and its fossil contents make it probable that, for the greater part, it was of sedimentary origin, and Profs. Daelter & Høernes record two analyses from the upper part of the mass in which the residue approaches 1 per cent.<sup>1</sup>

#### IV. THE MINERALOGICAL EVIDENCE.

About eighty of the specimens collected were sliced, with a view to the examination of any organisms which might be recognizable, and for the study of the mineralogical characters exhibited by the various limestones and dolomites. The results of the examination of the sections of Schlern Dolomite will be considered first, and afterwards the results obtained with rock-sections from other horizons will be stated briefly.

##### The Schlern Dolomite.

##### Area of the Schlern.

No. 7. Bedded dolomite, from the edge of the Schlern plateau.

Transverse and longitudinal sections of echinoderm-spines occur, while similarly-orientated coral-sections are recognized somewhat doubtfully, owing to loss of structure during dolomitization. Both allotriomorphic and idiomorphic crystals of dolomite are present, the idiomorphic crystals having cloudy centres. Minute iron-stained patches scattered throughout the section may represent finely-divided volcanic matter.

No. 8. About 500 feet below the edge of the Schlern plateau.

No organisms can be identified. The former presence of corals may perhaps be inferred from the meandrine arrangement of those dolomite-crystals which have regularly-arranged dark centres. Minute brown inclusions present are almost isotropic, and may be volcanic.

No. 10. About 800 feet below No. 8. (See Pl. XI, fig. 1.)

The section consists largely of allotriomorphic, dark-centred dolomite-crystals exhibiting a meandrine arrangement. Some minute opaque iron-stained fragments are to be seen.

No. 11. About 300 feet below No. 10.

No organisms have escaped the loss of structure consequent upon dolomitization. The section consists of allotriomorphic cloudy crystals of dolomite, with scattered fragments of magnetite and green augite, the latter being similar in appearance to the pyroxenic constituent of the tuffs and lavas of the Seiser Alp.

<sup>1</sup> Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) pp. 322, 323.

No. 12. About 300 feet below No. 11.

This is a submarine calcareous tuff. Numerous fairly-large and rounded fragments of a fine-grained decomposed basalt or melaphyre occur. Lath-shaped crystals of plagioclase and irregular fragments of magnetite are set in a brown structureless matrix, while steam-cavities are lined or filled with low-polarizing chlorite. Two or three basic types of basalt are present, some so dark in colour as to be almost opaque; others are much more felspathic, while some brown and almost isotropic palagonite-fragments occur. These are enclosed in a matrix consisting partly of clear calcite, partly of dolomite with regularly-arranged brown inclusions. The volcanic fragments are in contact indifferently with dolomite and with calcite. This association lends no support to the view that the volcanic fragments constitute the source of the magnesium present in the rock.

No. 13. This specimen occurs below No. 12, at the foot of the vertical cliff, and at the top of the talus-slope passed on the descent of the mountain towards Bad Ratzes.

The rock consists of a very fine-grained allotriomorphic dolomite, and contains no recognizable organisms.

β. Rolled block from the stream, just above Bad Ratzes. (See Pl. XIII, fig. 2.)

Dark-centred dolomite forms the bulk of the rock, and is arranged in a meandrine way which suggests the former presence of corals. The rock is cavernous, and the cavities have been lined by a secondary deposit of clearer dolomite deposited from solution, and showing alternate layers of clearer and more cloudy dolomite.

No. 31. Summit of the Rosszähne.

Much meandrine dark-centred dolomite is present, together with later-formed, bigger and clearer dolomite-crystals. Some small reddish fragments, possibly volcanic, are seen in the section.

No. 27. 'Cipit-dolomite' from a block on the Seiser Alp.

A fine-grained rock, consisting mainly of idiomorphic crystals with cloudy centres. Some of the rhombohedral kernels of the crystals have been removed, either by solution or by grinding when making the slice. A few reddish fragments occur, and are probably of volcanic origin.

#### Area of the Langkofl.

No. 95. Fallen block from the eastern flank of the mountain.

A rock which shows both concentric and radial structures in the hand-specimen, but radiating crystals only in section. No idiomorphic crystals are present.

No. 94. Material lining the eastern flank of the mountain.

A fragmental rock which, from its appearance and mode of occurrence on the flank of the mountain, is suggestive of a reef-talus. A dark calcareous cement embeds broken, idiomorphic, dark-

centred dolomite-crystals. Some of the dark centres of the crystals are composed of calcite, as they are stained by Lemberg's solution. The majority of the crystals are cavernous on a microscopic scale, and this gives the appearance of cloudiness to these individuals. One clear crystal of orthoclase, showing both cleavages, is to be noted, and exceedingly-minute, dark-reddish to opaque particles are possibly of volcanic origin.

No. 92. Above the bedded dolomite, at the head of the valley above Wolkenstein.

An allotriomorphic, slightly-cavernous dolomite. The former presence of meandrine organisms is indicated by the arrangement of the dolomite-crystals with dark centres.

#### Area of the Marmolata.

No. 35. Southern shore of the Fedaja See; from a height of 6500 feet.

A limestone crowded with small branching structures, which under the quarter-inch objective appear to be chambered.

A few dolomite-crystals and fragments of crystals are present. Some of these have regularly-arranged dirt-inclusions, while others consist of alternate zones of dolomite, calcite, and again dolomite. Meandrine patches of cloudy material represent decomposed organisms. Much of the calcitic groundmass is cloudy, and polarizes not in distinct crystals, but as an aggregate. Planes of movement and recrystallization are noticed in places. Where recrystallization has resulted in the formation of large twinned and cleaved crystals, these are in places found to be crowded with minute acicular bodies. At first these seem to be opaque, but when closely examined they are seen to be translucent.

One fragment, possibly volcanic, is present.

No. 34. West of No. 35 and lower down the valley, northern part of the Marmolata.

Similar generally to No. 35. The branching chambered structure is common. The section has been stained with Lemberg's solution, and some of the branching structures appear to be cavities in the slice filled with the stain, since they do not affect polarized light. The great majority, however, show polarization-colours, and, as is usual with organisms, they are stained more deeply than the background. Most of the slice consists of calcite, twinned and cleaved, and showing planes of movement and small veins of secondary calcite. A few crystals and fragments of idiomorphic dolomite occur. Some of the fragments look clastic, and extinguish not uniformly but as an aggregate, which would suggest that a secondary change in the mineral had occurred.

No. 33. A few feet above No. 34.

No dolomite is present, and planes of movement are very conspicuous. In other respects it closely resembles Nos. 34 & 35, and the branching structure is again common.

No. 32. From an immense fallen block, lower down the valley than No. 33. (See Pl. X, fig. 2.)

A large part of the slide consists of idiomorphic rhombohedral dolomite-crystals. The crystals are cloudy, with inclusions arranged parallel to their boundaries, and some of these inclusions are calcite. The rhombohedra are porous on a minute scale, and show the characteristic cleavages. The dolomite-crystals are set in a background of large platy crystals of calcite, which show lamellar twinning as well as cleavage. Signs of movement in the rock are common, and no organisms remain.

#### Area of the Sella.

The following specimens were collected from the slopes of the mountain, near the head of the Gröden Pass.

No. 101. Block fallen from above.

The greater part of the section is composed of cloudy allotriomorphic dolomite-crystals, often arranged in a circular manner and suggesting sections of corals. Empty spaces in the rock are lined and nearly filled with clearer and more idiomorphic crystals of the same mineral.

No. 100. Near the summit of the Gröden Pass. (Pl. X, fig. 1.)

Large areas of calcite include partly-disintegrated organisms resembling calcareous algæ (*Sphaerocodium* ?) which are only recognized by a 'dirt-line' marking the external boundary of the organism. A few dolomite-crystals occur within the calcite-areas, and are idiomorphic. Considerable areas of dolomite consist, however, of allotriomorphic crystals.

No. 99. Fifty feet below No. 100.

Very similar to No. 100. Large areas of calcite include imperfectly-preserved organisms, as well as a few rhombohedra of dolomite. A fair quantity of allotriomorphic dolomite-crystals is present, and includes irregular smaller patches of calcite, while exceedingly-narrow strings and bands of calcite traverse the dolomite-areas of the slide.

No. 98. St. Cassian Limestone, immediately below No. 99.

The rock consists mainly of calcite. The dolomite-crystals are well seen only under the quarter-inch objective, and are for the most part restricted to the matrix of one portion of the section in which unaltered sections of calcite-shells occur. The majority of the dolomite-rhomboheda have outer zones of chalybite, while a few have a middle layer of chalybite, the inner and outer portions consisting of dolomite alone.

#### The St. Cassian District.

Lavarella.—Collected from the cliff-face, in descending order.

No. 82. A cloudy, cavernous, fine-grained dolomite. The cavities in the rock are partly or wholly filled with large idiomorphic

dolomite-crystals showing dirt-zones. The remaining spaces are sometimes filled with a finer-grained mixture of calcite and small dolomite-rhombohedra, some of which show external zones of calcite.

No. 81. A very similar rock to No. 82. Meandrine organisms are indicated by the arrangement of dark-centred dolomite-crystals. Cavities in the rock have been subsequently filled with clear, coarsely-crystalline dolomite.

#### St. Cassian Limestones from St. Cassian.

No. 77. Above St. Cassian and below Lavarella. (Pl. XI, fig. 2.)

A well-preserved oolitic limestone. The oolitic grains are well formed, they show both concentric and radiating structure, and their centres in some cases consist of shell-fragments. For the most part, they are not in contact one with the other, but are separated by a cement of calcite in which are embedded numerous very minute rhombohedra of dolomite and chalybite (about  $\frac{1}{2500}$  inch in length). The dolomite and chalybite are practically restricted to the matrix of the rock, while later-formed cracks have been filled exclusively with calcite.

No. 76. A few feet below No. 77.

Irregular fragments of partly-disintegrated organisms<sup>1</sup> (including *Sphaerocodium Bornemannii* and other calcareous algæ) and pieces of limestone are embedded in a matrix of crystalline calcite. Minute crystals of dolomite occur scattered through the matrix, and some of them have outer zones of calcite. Cubes of pyrite, marginally altered to limonite, are abundant, and cracks traversing the slide are filled exclusively with calcite.

#### Sett Sass. (Schlern Dolomite.)

No. 112. Block fallen from the summit. (See Pl. XIV, fig. 1.)

The section consists of rounded bodies united by a granular dolomitie cement. The rounded bodies are most probably sections of organisms, possibly calcareous algæ (*Gyroporella*?), which have been completely dolomitized. Whereas the dolomite in the matrix is granular, that within the organisms consists of distinct rhombohedra with cloudy centres. It is noteworthy that dolomite formed by the alteration of a matrix of calcite-crystals is usually clear, while that formed by the alteration of organisms is almost invariably cloudy. The boundaries of the organisms are defined in this section by dolomite-crystals with very dark centres. Empty spaces occur within some of the organisms, and these cavities are lined with clearer secondary dolomite.

No. 107. Immediately below the junction with the Raibl Beds, northern end of Sett Sass.

The section consists mainly of cloudy dolomite, in which occur

<sup>1</sup> Kindly determined for me by Dr. G. J. Hinde, F.R.S.

irregular spaces and cracks filled with clearer secondary dolomite. Scattered through the rock are some crystals of pyrite, altered to oxide of iron.

No. 108. Base of Sett Sass, facing the Richthofen Reef.

Part of the slide consists of allotriomorphic, part of idiomorphic crystals of dolomite, with regularly-arranged dark centres, set in a matrix of a muddy-looking material. Cracks have been filled with clear allotriomorphic secondary crystals, while a little pyrite with an aureole of iron-oxide is also noticeable.

#### The Richthofen Reef.

No. 110. From the outer face of the Richthofen Reef.

The rock has a cloudy granular matrix, in which are seen large cloudy rhombohedra of dolomite with light borders. Irregular cavities are lined with large, clear, secondary dolomite-crystals.

#### St. Cassian Limestone from Sett Sass.

No. 109. St. Cassian Limestone with corals (?), between Sett Sass and the Richthofen Reef. (Sec Pl. XII, fig. 2 & Pl. XIII, fig. 1.)

The slide consists mainly of a transverse section of a coral; and a longitudinal section of one of the calcareous algæ, probably *Sphaerocodium*, is also present. The coral is embedded in a matrix of calcareous mud, part of which still remains, but most of it has clarified by recrystallization as a clear mosaic of calcite. This muddy matrix has served to prevent the degradation of the coral, the structure of which, for the most part, is wonderfully preserved. The original aragonite-fibres of the stereoplasm, the brown colour of the septa, the centres of calcification, and even the secondary aragonite, subsequently deposited in optical continuity with the coral-fibres, remain unaltered. The appearance of the coral in section is such, that it is difficult to believe that one is dealing, not with a coral from an unaltered modern reef, but with one of Triassic age.

#### The Cortina District.

##### Col Crepa.

No. 49. Top of the western part of Col Crepa.

While the section shows a certain amount of a fine, granular, dark matrix, most of the slide is comprised of clear allotriomorphic dolomite-crystals, in which no organisms can be detected.

No. 51. Slickensided and brecciated rock from a fault-plane, few yards below No. 49.

Large and small, composite, angular fragments of clear dolomite are set in a fine dolomitic matrix. The larger fragments consist of several allotriomorphic crystals, and some of these show evidence of lamellar twinning in polarized light, a very unusual occurrence in dolomite.



No. 62. Top of the north side of Col Crepa.

A clear allotriomorphic dolomite, showing no signs of organic structure, except in some parts of the section where cloudy crystals are arranged in a meandrine fashion, suggesting the former presence of corals.

No. 64. A rock very similar to No. 62, a few feet below it.

Giau Pass.

No. 37. From the Giau Pass, about 6 miles south-west of Cortina. Not in place.

The slide shows a section of a coral preserved mainly in calcite. The structure of the coral is nearly obliterated; the external wall can, however, be traced, and the septa are defined by linear bands of dolomite- and calcite-crystals. Scattered through the coral occur a large number of minute, perfectly-idiomorphic crystals of quartz (see Pl. XIV, fig. 2). They are doubly terminated, and can be recognized by their shape, their grey polarization-colours, and their positive sign, when examined with a quartz-wedge. Unlike the quartz-crystals found in the Carboniferous Limestone of Derbyshire and other areas, they are not cloudy with inclusions, but perfectly clear and translucent. The longer diameters measure from  $\frac{1}{800}$  to  $\frac{1}{1500}$  inch. These crystals probably represent the colloid silica of the skeletons of the siliceous organisms originally present in the rock, which has been recrystallized.

Many of the dolomite-rhombohedra show minute bands of calcite extending through them, and coinciding in general with the directions of the cleavage-lines but extending slightly on either side. They possibly represent spaces formed by solution along cleavages, and subsequently filled with calcite. Staining with Lemberg's solution, and examination with the quarter-inch objective, causes these calcite-bands to be visible as fine pink lines.

The Hexenfels.

No. 56. From the base of the Hexenfels, near Falzarego Pass.

A clear dolomite, partly granular but mainly allotriomorphic. No organisms are visible, and specks of oxide of iron occur sparingly.

Travernanzez Valley.

No. 59. Near the junction with the Raibl Beds, just below the Col du Bec.

A clear coarse-grained dolomite, devoid of organisms.

Sorapis.

No. 55. Schlern Dolomite from the flanks of Sorapis, 1 mile north of San Vito del Cadore.

A fairly coarse-grained dolomite, devoid of organisms. Specks of a compound of iron are scattered through the section.

### Monte Cristallo.

No. 46. South side of Monte Cristallo, immediately below the Raibl Beds.

The crystals of dolomite have dark centres. No organisms are recognizable; but darker areas possibly represent shell-sections.

### Tre Croci.

No. 40. From an exposure of dolomite, east of Tre Croci.

Sections of ill-preserved organisms may represent calcareous algæ. The matrix of the rock is cloudy and granular.

No. 41. From 50 feet below No. 40.

A coarsely-crystalline, rather cloudy dolomite, containing no traces of organisms.

### The Dürrenstein Area.

No. 66. From the summit of the Dürrenstein (9300 feet).

An almost clear, cavernous, coarsely-crystalline dolomite, devoid of organisms.

No. 68. About 500 feet above the Dürrenstein Hotel.

A fine-grained, rather cloudy dolomite, in which darker, more or less circular areas may represent the remains of calcareous algæ.

### The Drei Zinnen Area.

No. 71 A. Block in a stream at the head of the Rienz Valley.

Broad areas of clear, coarsely-crystalline dolomite occur, with dark areas of smaller cloudy crystals arranged in a more or less meandrine way, and suggesting the former presence of corals.

No. 70. From the head of the Rienz Valley, the northern base of the Drei Zinnen.

Much of the section consists of cloudy dolomite. Cavities are lined or filled with more coarsely-crystalline, clearer dolomite.

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Sections from calcareous rocks both above and below the horizon of the Schlern Dolomite were made, and descriptions of some of the more important rocks are here appended.

### Below the Schlern Dolomite.

#### Wengen Limestone.

#### Seiser Alp.

No. 22. From the ravine just below the Selaus Alp Hut, Frombach.

A rock consisting mainly of small patches of granular calcite, fragments of shells, and of very-finely divided volcanic fragments, grey-brown in colour, and polarizing as an aggregate. Some elongated opaque particles scattered through the section are seen, on examination by reflected light, to consist of pyrite.

## Buchenstein Limestone.

No. 18. A hard compact rock, interbedded with a siliceous nodular limestone, above Bad Ratzes.

The groundmass of the rock-section consists of structureless calcite, in which various organisms occur. These appear to be dolomitized, since they are not stained with Lemberg's solution. The most abundant form is long and curved, and probably represents cross-sections of thin-walled shells. Some of the bodies are somewhat oval, and may represent tangential sections of shells. Cross-sections of minute tubules are also present, and a section of a foraminifer is to be seen as well. One crystal of biotite was recognized in the slide.

Analysis shows that only 3.4 per cent. of magnesium-carbonate is present in the portion analysed; but examination of the rock-section shows that the amount present in places must be considerably in excess of the figure obtained by analysis.

No. 88. Nodular limestone from the Gader Gorge, north of St. Leonhard. (See Pl. XII, fig. 1.)

The rock has a granular matrix of calcite, in which various organisms preserved in calcite are embedded. These include a rotaline foraminifer, shell-sections, calcareous algæ, and other meandrine bodies, the precise nature of which cannot be determined. Along cracks the limestone has been altered by infiltrated water bearing salts of iron and magnesium; and as a consequence, pyrite, chalybite, and dolomite have been deposited in the immediate neighbourhood of the fractures.

The dolomite-crystals are all zoned, and most of them consist of alternate layers of dolomite and chalybite, although staining shows that some of the crystals consist of alternate zones of dolomite and calcite.

## Mendola Dolomite.

No. 19. Above Bad Ratzes, and below No. 18.

A compact dolomite, consisting entirely of allotriomorphic crystals, showing no trace of organic structure.

## Lower Muschelkalk.

No. 86. Gader Gorge, north of St. Leonhard.

The groundmass consists of calcite-crystals, some of which are twinned. Sections of shells are numerous; many angular quartz-grains occur; while some flakes of muscovite and one or two crystals of decomposed pyrite are also to be seen.

## Above the Schlern Dolomite.

## Dachstein Dolomite.

No. 1. From the summit of the Schlern (8400 feet).

A dolomite composed of allotriomorphic crystals. The only

traces of organisms are dark meandrine areas scattered through the section.

No. 42. From the fault-valley of Monte Cristallo, just below Tre Croci.

A compact, rather fine-grained dolomite, formerly crowded with organisms, of which only the 'ghosts' or dark outer borders can now be traced. Shells and meandrine forms constitute the most abundant organisms.

#### Raibl Deposits.

No. 4. Red dolomite from the Schlern plateau, below Burgstall.

A somewhat ferruginous, coarse-grained dolomite. Most of the crystals have dark reddish centres, and some of the iron is concentrated along definite lines or cracks. No organisms are recognizable.

No. 73. Below the military post, on the Dürrenstein massif.

The section consists of a transverse section of a coral, preserved in calcite and embedded in a fine-grained homogeneous matrix of dolomite.

No. 58. Near the summit of the Col du Bec, between Monte Tofana and Lagazuoi; near the base of the Raibl Beds.

A fragmental rock, made up of rounded pieces of somewhat iron-stained dolomite, together with some rounded basalt-fragments, all set in a matrix of dolomite. Some crystals of clear felspar are scattered through the rock. They show extinction-angles up to  $20^\circ$  from prism-edges, and sometimes include cubes of rock-salt.

Irregular, clear, secondary quartz fills cavities in the rock. The quartz is traversed generally by almost rectangular cracks, and has inclusions of gas-bubbles, and also of clear idiomorphic rhombohedra of dolomite(?).

No. 106. Just above the Schlern Dolomite, northern end of Sett Sass.

A fragmental rock, composed mainly of small pieces of a spherulitic rhyolite showing an irregular radial structure. Secondary quartz is present, and contains inclusions of rock-salt, gas-bubbles, and dolomite(?)—rhombohedra. Felspars are also present, one of which shows simple twinning, and many contain included rhombohedra of dolomite(?). A fragment of chlorite, too, is present, and the rock has a small quantity of a calcareous or dolomitic cement.

#### V. ORGANISMS RECOGNIZED IN THE LIMESTONES AND DOLOMITES.

Many observers have studied the organic remains from the various deposits of the Alpine Trias. Naturally, the richly-fossiliferous St. Cassian Limestone has been most narrowly examined, and the varying lithological and palæontological characters of the Raibl deposits have also been closely studied. The Dachstein, Schlern, and Mendola Dolomites have received less attention from palæontologists, because fossils are far less commonly found, except in those

areas where the rocks have not been dolomitized. My collection was made, primarily to illustrate the chemical and mineralogical characters of the rocks from various horizons; so that most of the fossils recognized were those met with in the examination of thin sections from the limestones and dolomites.

### The Schlern Dolomite.

Very few of the hand-specimens of Schlern Dolomite contain recognizable organisms. Corals are occasionally found in the mass of the rock from various horizons. They are almost always found as casts in dolomite, and only in a few places occur in abundance. In thin sections the calcareous algæ are the commonest fossils, especially various species of *Gyroporella* (*Diplopora*). Echinoderm-spines and lamellibranch-shells are not uncommon here and there; while foraminifera are occasionally found.

Sections of 38 specimens of Schlern Dolomite were examined under the microscope, and only one coral was recognized with certainty; while eleven other sections showed meandrine areas of cloudy dolomite, which might represent corals, but the loss of structure during dolomitization had been so great that not much confidence could be placed in their identification. Calcareous algæ were recognized in three sections, and organisms doubtfully referable to them occurred in five other slides. Sections of shells (probably lamellibranchs) and echinoderm-spines were each recognized in single slides. No less than seventeen sections of the dolomites, representing about 45 per cent. of the sections examined, failed to yield any traces of organic structure.

### Deposits below the Schlern Dolomite.

#### St. Cassian Limestone.

Four sections were examined, and fossils were found to be more abundant and better preserved than in the dolomitized strata. In one section, a coral was seen, the structure of which was perfectly preserved in its original aragonite. Two sections contained numerous examples of more than one genus of calcareous algæ. Three of the sections showed fragments of shells, probably lamellibranchs; while one section contained the chambers of one of the foraminifera and also a tubular organism, probably a polyzoon.

#### Wengen Beds.

But one section was examined, and the only recognizable organisms were lamellibranchs.

#### Buchenstein Limestone.

Two sections were cut: algæ occurred in one, lamellibranchs in the other, and foraminifera in both.

## Mendola Dolomite.

Examination of a single specimen failed to show any trace of organisms.

## Lower Muschelkalk.

Lamellibranchs were noticed in the only section examined.

## Deposits above the Schlern Dolomite.

## Dachstein Dolomite.

Two sections were examined, and it was found that one slide contained remains of what were probably lamellibranch-shells, while both sections showed meandrine structures which were possibly the remains of corals.

## Raibl Beds.

Four sections were cut; of these, one showed the transverse section of a compound coral, while the other three were apparently devoid of organisms.

VI. RELATIONS BETWEEN THE FOSSILS AND THE ORIGIN  
OF THE ROCKS CONTAINING THEM.

Before attempting to interpret the results arising from the examination of the fossil contents of these rocks, especially of the Schlern Dolomite, it will be convenient to consider briefly our present knowledge as to the organisms composing coral-limestones, and the changes that they undergo.

In the first place, it has been shown that corals play a much less important part in building up coral-reefs than was formerly supposed.<sup>1</sup> Calcareous algæ are often more abundant than the corals; foraminifera and echinodermata often bulk largely; and polyzoa, lamellibranchiata, and other organisms are occasionally present in fair abundance.

The sequence of mineralogical and structural changes which coral-limestones undergo—a subject originally studied by Dr. Sorby—has in recent years been rather closely investigated. I have already dealt with some of the more striking changes occurring in upraised coral-islands<sup>2</sup>; while Dr. C. G. Cullis<sup>3</sup> has examined in greater detail the mineralogical constitution and structural changes in thin sections of the rocks from the Funafuti boring.

It is found that organisms, the skeletons of which are composed of aragonite, are abundant in the most recent limestones, but gradually become recrystallized as calcite; and this change is accompanied by a loss of structure in the organism. For this reason, all the reef-forming corals, the gasteropoda, and some of the calcareous algæ,

<sup>1</sup> R. L. Sherlock, *Bull. Mus. Comp. Zool.* vol. xxxviii (1903) p. 349; E. W. Skeats, *ibid.* vol. xlii (1903) p. 53; & G. J. Hinde, 'Funafuti Report' *Roy. Soc.* (1904) p. 332.

<sup>2</sup> *Bull. Mus. Comp. Zool.* vol. xlii (1903) p. 53.

<sup>3</sup> 'Funafuti Report' *Roy. Soc.* (1904) p. 392.

such as *Halimeda*, are much less readily recognized in thin sections of limestones in which this change has taken place. When, as not infrequently happens, dolomitization of the limestones occurs, not only are all traces of the organisms previously mentioned generally obliterated, but the more stable organisms with calcite-skeletons, like the echinodermata, the foraminifera, and most of the calcareous algæ, begin to lose structure, owing to the invasion of crystals of dolomite. In general, the more complete the dolomitization, the more complete is the destruction of the organisms composing the rock, until a perfectly-structureless, homogeneous dolomite may be formed. In recent coral-limestones these changes can be traced gradually in a succession of sections; but the early stages in the life-history of the Triassic dolomites of Southern Tyrol are closed. All the rocks are altered. Where they are not dolomitized, they have been recrystallized as the result of earth-movements; and where the rocks are undisturbed, dolomitization has been so complete that many of the rocks are dolomites of theoretical composition. In recent coral-limestones the rocks are often quite devoid of organisms; and it is therefore not surprising to find in rocks of Triassic age, which are often more completely dolomitized than any recent limestone, that organisms are always scarce, and in 45 per cent. of the sections are apparently unrepresented.

It will be seen that, with regard to the origin of the Schlern Dolomite, the evidence afforded by a consideration of its organic contents alone is inconclusive. The question is not whether the Schlern Dolomite was originally a coral-limestone entirely composed of corals, but whether or no it was a coral-limestone of a more common type (of which Funafuti and Christmas Island yield examples), wherein calcareous algæ and foraminifera bulk largely, while corals occupy an important but relatively-subordinate position. It is not possible to say definitely from this evidence that it was originally a coral-limestone; on the other hand, it seems to be equally unsafe to conclude with some geologists that the comparative absence of corals in the present condition of the rock proves that they were never present in the original limestone. The solution of the question as to the origin of the Schlern Dolomite should be sought on other than palæontological evidence, which, so far as it goes, does not preclude the possibility of the deposit having originated as a coral-limestone.

## VII. MINERALOGICAL STRUCTURES AND CHEMICAL CHANGES IN THE LIMESTONES AND DOLOMITES.

### Mineralogical Structures.

The examination of numerous thin sections from recent coral-limestones<sup>1</sup> has served to show that, in general, three types can

<sup>1</sup> E. W. Skeats, *Bull. Mus. Comp. Zool.* vol. xlii (1903) pp. 105 *et seqq.*; & C. G. Cullis, 'Funafuti Report' *Roy. Soc.* (1904) p. 404.

be recognized, each being characterized by some mineralogical peculiarity.

1. Many of the more recent limestones, while consisting largely of calcite, contain also organisms, the skeletons of which consist of aragonite; and not infrequently secondary aragonite has been deposited in crystallographic continuity with the aragonite of the organism.
2. Gradual alteration and recrystallization of the first type of limestone leads to the production of a rock in which organic remains and matrix alike consist entirely of calcite.
3. The replacement of calcium-carbonate by magnesium-carbonate in limestones either of Type 1 or Type 2 leads to the formation of a third type, characterized by the presence of crystals of dolomite; in some cases, the replacement proceeds so far that the limestone is entirely converted into dolomite.

(1) Examination of many sections of rocks belonging to the horizon of the Schlern Dolomite shows that the first type of limestone, characterized by the presence of aragonite, is now wanting. The St. Cassian Limestone of Sett Sass, however, provides a very interesting example of the aragonitic type of limestone. A section of a coral, when examined under a high power, shows a remarkable preservation of the original aragonite-fibres of the coral and of the secondary aragonite formed in crystallographic continuity with them. With this single exception, none of the rocks examined contained any crystals of aragonite.

(2) The Marmolata massif affords good examples of limestones consisting entirely of the mineral calcite. The rocks have been much recrystallized as a result of earth-movements, so that lamellar twinning is very common in the calcite-crystals, which are generally allotriomorphic. Many of the St. Cassian Limestones also consist entirely of calcite and calcite-organisms.

(3) Among the rocks in which the mineral dolomite occurs we have:—

( $\alpha$ ) Dolomitic limestones, and ( $\beta$ ) Dolomites proper.

In rocks belonging to the group  $\alpha$  magnesium-carbonate generally forms from 10 to 30 per cent. of the mass, so that a larger or smaller amount of calcite is always present. In these limestones, the dolomite-crystals are generally markedly idiomorphic. One of the Marmolata rocks (No. 32) shows fine idiomorphic dolomite-crystals, surrounded by a matrix of calcite (Pl. X, fig. 2). The same feature is seen on a minute scale in No. 77, one of the St. Cassian oolitic limestones, in which tiny rhombohedra of dolomite occur, and are restricted to the matrix of the rock (Pl. XI, fig. 2). No. 34, one of the Marmolata rocks, is a limestone containing broken fragments of dolomite-crystals which have no definite extinction, and are possibly of detrital origin. No. 37, a dolomitic limestone from the Giau Pass, contains a longitudinal section of a coral with dolomite-crystals deposited in a



definite arrangement within the coral. What is still more interesting, is the occurrence within the mass of the coral of extremely-minute, perfectly-clear, doubly-terminated quartz-crystals, which constitute about 1 per cent. of the rock (Pl. XIV, fig. 2).

When the dolomitization of a limestone is nearly complete, it is noticed that the dolomite-crystals mutually interfere, so that the crystals are mainly allotriomorphic. Among the Schlern rocks, No. 7 affords a good example of a rock approximating to a dolomite of theoretical composition, and containing both idiomorphic and allotriomorphic crystals.

With the production of a pure dolomite, the rock usually becomes quite structureless and the crystals almost entirely allotriomorphic. No. 56, from the Hexenfels, is a good example of this type of dolomite.

Dolomite-crystals are sometimes quite clear and transparent. More generally, however, they are seen to contain cloudy matter; and this is generally orientated within the crystal, sometimes constituting a dark centre, sometimes being arranged in one or more zones parallel to the rhombohedral outline of the crystal. These cloudy centres and zones may originate in several different ways.

Prof. Watts has shown, in the case of the dolomites of the Carboniferous Limestone,<sup>1</sup> that this cloudy material is insoluble matter caught up and regularly arranged during the growth of the crystals.

My own observations indicate four additional causes :—

1. In some dolomites, staining with Lemberg's solution has shown that the cloudy matter is calcite.
2. In other dolomites, especially those of theoretical composition, there is little doubt that the cloudy matter consists of finely-divided dolomite, which does not stain with Lemberg's solution.
3. In some of the St. Cassian limestones the dolomites are zoned with cloudy chalybite, more or less altered to iron-oxide.
4. Occasionally, these cloudy areas, when examined under a high power, have been seen to be due to numerous minute cavities in the crystals. There is no direct evidence to show whether these cavities are original, or due to subsequent solution of certain parts which, owing to their physical state or chemical composition, were more susceptible to the solvent action of sea-water. Their irregular distribution in the parts of the crystals in which they occur is against the latter view of their origin.

Quite apart from the zoning in dolomite-crystals produced by this

<sup>1</sup> 'Geology of the South-Wales Coalfield, pt. ii: The Country around Abergavenny' Mem. Geol. Surv. (1900) pp. 34-36.

cloudy material, another type of zoning is occasionally seen<sup>1</sup> both in dolomites from Mango (Fiji), and also on a smaller scale in certain of the Tyrol dolomites. Before a rock is stained, it may appear to contain perfectly-homogeneous, clear, idiomorphic crystals of dolomite. Staining with Lemberg's solution shows, however, that the crystal is composite in character, and is composed of alternate layers of calcite and dolomite (less frequently chalybite forms one of the mineral-layers). The layers are in optical and crystallographic continuity, and the whole appears to form a single crystal.

### Chemical Changes in the Limestones and Dolomites.

Compared with recent coral-limestones, these Triassic rocks present one or two interesting, if minor, points of difference:—

1. Only very minute traces of calcium-phosphate are found. In coral-limestones .2 per cent. is a fairly-common amount, and occasionally beds of phosphate are met with, as at Christmas Island. The circumstance that the earliest bird so far discovered is of Kimeridge age, is sufficient to account for the absence of beds of limestone altered to phosphate in the area of the Dolomites.
2. Recent coral-limestones show no trace of silicification. This is remarkable, in view of the fact that among the living organisms present in coral-reefs, siliceous forms sometimes constitute at least 1 per cent. of the whole. The colloid silica of which their skeletons are composed must be peculiarly soluble under the conditions existing in a coral-reef, for no trace of siliceous organisms has ever been found in a recent coral-rock. The same is true of the Tyrol limestones and dolomites, with the significant exception of the quartz-crystals occurring in the coral-section of No. 37. This quartz may represent the colloid silica of siliceous organisms, redeposited in the crystalline state.
3. In the Tyrol dolomites dolomitization is often more complete than in the case of any recent coral-limestone. From Christmas Island<sup>2</sup> and from the Funafuti boring, two dolomites which were analysed gave just over 43 per cent. of magnesium-carbonate; but, in general, a condition of stability ensued when the percentage of magnesium-carbonate amounted to about 40. Many of the Tyrol rocks are pure dolomites, containing 45.65 per cent. of magnesium-carbonate, but no rock has been found to exceed the latter amount.

<sup>1</sup> E. W. Skeats, Bull. Mus. Comp. Zool. vol. xlii (1903) pp. 117-18.

<sup>2</sup> *Ibid.* pp. 96, 162.

### Formation of the Dolomites.

The most important chemical problems in Southern Tyrol are, perhaps, the following:—

1. The mode of origin of those wide-stretching and thick masses of dolomite, of which the Schlern Dolomite is the most conspicuous example.
2. A second problem is encountered in the attempt to explain the circumstances under which some areas, such as the Marmolata massif, escaped dolomitization, while most of the limestones of the same age are almost completely dolomitized.
3. The association of some of the dolomites of the Raibl Beds with gypsum-deposits suggests a different origin for these rocks.
4. The local dolomitization of some of the St. Cassian limestones along cracks in the rock would seem to require a special explanation.

The early views of L. von Buch on the origin of dolomite were formed as a result of the examination of the dolomites of the Tyrol, and they involved the ascent of heated magnesium-vapour from the outpourings of the Triassic volcanic rocks, which are found in association with the dolomites. Modern chemists would not agree with the chemical reactions involved in such a process, and, apart from this, the distribution of the dolomites has no causal relation to the distribution of the volcanic rocks.

The analysis by Silliman, of a dolomitized limestone from the raised coral-island of Makatea, led Dana to propound the view that sea-water constituted the source of the magnesium, and that it was probably introduced from the concentrated waters of the lagoon. This view forms the basis of the modern explanations of the formation of such dolomites.

In some of the Tyrol limestones examined by me, magnesium-carbonate is present in the rocks, in varying amounts up to 6 or 7 per cent., without leading to the formation of visible dolomite-crystals. In a paper published in 1903,<sup>1</sup> I quoted analyses from rocks at Christmas Island and elsewhere, in which limestones containing over 11 per cent. of magnesium-carbonate were similarly devoid of visible dolomite. Following Dana, I believe that the magnesium is introduced from the sea-water, and is absorbed by calcite up to 10 to 15 per cent. of its mass without any visible change of form, but above that amount the stable compound dolomite crystallizes out.<sup>2</sup> A similar result was obtained on analysing specimens from the upper part of the Funafuti borings.<sup>3</sup>

<sup>1</sup> Bull. Mus. Comp. Zool. vol. xlii (1903) p. 102.

<sup>2</sup> Mr. L. J. Spencer has described somewhat analogous behaviour in the mutual relations of copper and silver-iodides, Min. Mag. vol. xiii (1901) pp. 43-44.

<sup>3</sup> J. W. Judd, 'Funafuti Report' Roy. Soc. (1904) pp. 373 *et seqq.*

In this case as much as 16 per cent. of magnesium-carbonate is present in the rock, and no dolomite-crystals can be traced. Prof. Judd gives a different explanation of the presence of so much magnesium-carbonate in the rock—an explanation depending on the relative solubilities of the two carbonates in sea-water. He quotes Gustav Bischof's and Högbom's experiments in support of the view that under atmospheric pressure calcium-carbonate is much more soluble than magnesium-carbonate. The skeletons of calcareous organisms contain in the living state a small amount of magnesium-carbonate, sometimes reaching 1 per cent. in amount. If, then, the rock composed of such organisms is attacked by water bearing carbon-dioxide in solution, calcium-carbonate will be dissolved more quickly than magnesium-carbonate, and the percentage of magnesium-carbonate in the remainder will as a consequence be raised, and may eventually reach 16 per cent. In this way, Prof. Judd explains the composition of the Funafuti rocks between the limits of 20 to 50 feet below the surface of the water.

This process of differential solution is one which no doubt coral-limestones undergo to a greater or smaller extent, and it is probably the correct explanation of the origin of the all but structureless limestones containing magnesium-carbonate in insufficient amount for the production of dolomite-crystals. Very extensive solution and removal of calcium-carbonate is needed, however, before the percentage of magnesium-carbonate in the residual rock is appreciably raised. Assuming the original limestone to contain 1 per cent. of magnesium-carbonate, an amount which is probably near the superior limit for the fresh organisms composing the rock, and further, assuming that only the calcium-carbonate is dissolved by carbonated water, 80 per cent. of the original rock must be removed by solution before the magnesium-carbonate in the remainder reaches 5 per cent., 90 per cent. must be dissolved before the magnesium-carbonate reaches 10 per cent., and over 93 per cent. before the magnesium-carbonate reaches 16 per cent. So extensive a removal of the original substance of the rock would largely destroy the structure of the organisms that it contained. In the case of the limestones from Christmas Island, Niue, and elsewhere, examined by me, in which magnesium-carbonate was present in the rock in amounts up to 11 per cent., the structure of the contained organisms was in general wonderfully preserved; and not only was there no evidence of solution in the rock, but on the contrary secondary calcite and secondary aragonite were deposited upon the organisms to a considerable extent. I was, in consequence, forced to the conclusion that in these limestones the magnesium-carbonate was introduced into the rock from the sea-water, resulting in the partial replacement of calcium- by magnesium-carbonate.

Prof. Judd suggests that the conversion of a magnesian limestone containing about 15 per cent. of magnesium-carbonate, into a rock containing 40 per cent. or more of that carbonate, may be due

to the operation of the forces of segregation, forces which are concerned in the formation of concretionary structures like the septaria in the London Clay and the 'doggers' in the Oolites.

Prof. Garwood,<sup>1</sup> in 1891, published the results of his investigations 'On the Origin & Mode of Formation of the Concretions in the Magnesian Limestones of Durham.' He showed that certain bands in the rock have practically the composition of dolomite, while in other layers, by subsequent solution, segregation of the calcium-carbonate has been set up, and concretionary structures are formed which consist mainly of calcium-carbonate. Prof. Garwood's results are interesting in this connection, because the effect of the segregative forces in the formation of the concretions is not the enrichment by magnesium-carbonate of a slightly-magnesian limestone, but the dedolomitization of a rock which formerly had almost the composition of a dolomite. Under other conditions than those obtaining in the Magnesian Limestone of Durham, it is quite possible that the calcium-carbonate may be removed altogether by solution, and that segregation of the remaining mass will give rise locally to the formation of dolomite. In some localities where dolomitic limestones are found, their occurrence is often of a patchy character, the dolomite disappearing horizontally and vertically in a short distance. It may very well be that some of these occurrences of dolomite could be best explained by a process of segregation, especially as in general the effects of the segregative forces (as exemplified by septaria and 'doggers') are of a quite local character.

In the Dolomites of the Tyrol, however, the dolomitization is not local, but on a very extensive scale. The Schlern Dolomite extends over many square miles, and in places exceeds 3000 feet in thickness, so that no local cause can explain its production over such large areas. The rock was without doubt originally a limestone, composed entirely of organisms, and was subsequently converted into dolomite. There can be no question that the magnesium was obtained from the sea-water. Chief interest is centred in the conditions under which this partial replacement of calcium-carbonate by magnesium-carbonate took place.

The Tyrol rocks are so completely dolomitized that they do not, of themselves, afford much indication of the conditions under which they were formed. Examination of specimens from upraised coral-islands, such as Christmas Island, the Fijis, etc., led me to the conclusion that the formation of dolomite can proceed in quite shallow waters.<sup>2</sup> In Christmas Island a band of dolomite occurs immediately below beds of calcium-phosphate, which cap the highest points of the island. These were low islets in the ancient lagoon, on which bird-droppings fell. The occurrence of dolomite immediately beneath these phosphate-beds points to its formation in superficial waters. Many of the Fiji islands are also dolomitized

<sup>1</sup> Geol. Mag. 1891, pp. 433-40.

<sup>2</sup> Bull. Mus. Comp. Zool. vol. xlii (1903) p. 125.

at their summits; some of their fringing-reefs, too, are dolomitized, while the raised fringing-reefs along the coasts of the Red Sea are also occasionally dolomitized. Dana was of opinion that magnesium was introduced into the rock from the waters of the lagoon during concentration. Many lagoons, however, are quite open to the sea, and concentration of the water is not possible in most of them; while, on the other hand, the outer parts of fringing-reefs facing the open ocean are sometimes dolomitized.

My view, then, is that the Schlern Dolomite originated first as a limestone, composed of organisms, in a slowly-subsiding area. Dolomitization of the limestone in superficial waters kept pace with the slow subsidence, so that the whole thickness of 3000 feet or more of rock was continuously and uninterruptedly converted into dolomite during the Triassic Period. Some areas in the Tyrol are only partly dolomitized, while others, like the Marmolata, are for the most part undolomitized limestones.

One important factor in the dolomitization of a limestone is the time during which the limestone is submitted to the conditions producing dolomitization. If it be true that dolomitization of submerged limestones takes place in shallow water, then the extent to which a limestone can be dolomitized will depend, other things being equal, upon the length of time during which the limestone remains in shallow water, that is, upon the rate of subsidence or elevation of the mass. Complete dolomitization will only be effected under stationary conditions in shallow water, or as a result of a very slow subsidence or elevation; while, conversely, a limestone which is raised or lowered comparatively rapidly, may undergo no dolomitization.

The problem is certainly complicated by other considerations. Among these, an important question is the extent to which the rock is permeable to sea-water. The growing part of the reef just below the surface is generally very porous, and admits of the free penetration of sea-water, and sometimes the older part of the limestone is also sufficiently porous to admit of the introduction of water throughout its mass. Perhaps more generally, however, that part of the structure upon which the living reef rests loses its porosity, and is converted into a dense limestone by the filling-up of the cavities by detrital material, or the fine mud produced by the partial solution of the loosely-consolidated upper part of the rock. Since the conversion of such a limestone into dolomite is effected by an interchange between magnesian salts in sea-water and the calcium-carbonate of the rock, it follows that the production of a compact rock is one of the factors which shields a limestone from dolomitization. Prof. Branner has adopted this view, in order to explain the local character of the dolomitization of the Brazilian reefs.<sup>1</sup>

I think that the varying power of sea-water to dissolve limestones is another factor in the question of the formation of dolomite. This power depends mainly upon the amount of carbon-

<sup>1</sup> Bull. Mus. Comp. Zool. vol. xliv (1904) p. 265.

dioxide dissolved in the water, or liberated on the decay of the organisms composing the rock. Probably the interchange of magnesian for calcium-salts is most readily effected at the moment of solution of the calcium-carbonate of the rock. If this be so, the carbon-dioxide slowly liberated on the decay of plants and animals would help to determine the introduction of magnesium. We should, in that case, expect that unstable forms like the corals would be more rapidly affected than organisms the skeletons of which are built of calcite; and among the calcite-forms we should expect those to be most dolomitized which contain the largest quantity of organic matter in their tissues. Examination of thin sections of coral-limestones affords evidence in favour of this view, since aragonite-forms, like the corals, and *Halimeda* among the calcareous algæ, contain much organic matter in their tissues, and are the first organisms to suffer dolomitization and loss of structure. Among the calcite-organisms, too, we find that forms such as foraminifera and echinoderm-spines, containing little organic matter in their skeletons, resist disintegration and dolomitization longer than *Lithothamnion* and *Lithophyllum* among the calcareous algæ.

So far, the evidence given of the distribution of dolomite in limestones of organic origin points to the change having taken place in shallow water, while contributing causes are porosity of the limestone, slow upheaval or subsidence, and the presence of carbon-dioxide in the water, to serve as a solvent for part of the limestone. What, however, are the precise conditions governing the change from limestone to dolomite in the case of great rock-masses, and the exact chemical reactions which take place, it is very difficult to say. Chemists are not all in agreement as to the relative solubilities of the two carbonates in carbonated water, and it may be that the reactions which take place in pure water are modified in sea-water. There is, however, considerable evidence to show that under atmospheric pressure calcium-carbonate is more soluble than magnesium-carbonate. Similarly, there is no doubt that, when dolomite is subjected to fresh water containing carbon-dioxide at a pressure of about 5 atmospheres, the magnesium-carbonate is dissolved and the calcium-carbonate remains almost unaffected. This, indeed, was the process formerly employed in the production of Epsom salts from magnesian limestone. It would appear to follow, then, that at some pressure between 1 and 5 atmospheres carbonated water will dissolve the two carbonates in molecular proportions, and under saturated conditions the double carbonate, dolomite, may be deposited. In this connection it may be stated that Mr. Stanley Gardiner has quoted experiments showing that dolomite is more insoluble in carbonated water than either calcium-carbonate or magnesium-carbonate alone.<sup>1</sup> The change from calcite to dolomite involves a considerable shrinkage in the bulk of the rock, amounting to about  $\frac{1}{11}$ th of the original mass. In view of this contraction, it is quite in accordance with

<sup>1</sup> Proc. Camb. Phil. Soc. vol. ix (1898) p. 496.

the well-established 'principle of least work' to find that this change is facilitated by an increase of pressure.

Translated into depths, the limits may be expected to lie between the surface and 150 feet below it, and probably nearer the upper than the lower limit. The solid matter in solution in sea-water consists of 78.32 per cent. of sodium-chloride, 1.69 per cent. of potassium-chloride, 9.44 per cent. of magnesium-chloride, 6.40 per cent. of magnesium-sulphate, 3.94 per cent. of calcium-sulphate, and traces of bromine, iodine, etc. What we require to know are the conditions under which the magnesium-chloride and sulphate present in such considerable amount in sea-water will react with the calcium-carbonate dissolved by carbon-dioxide and in contact with the mass of the limestone. Dr. C. Klement's experiments<sup>1</sup> demonstrate that this reaction can take place under pressure, and at a temperature of about 100° C. He subjected calcite, aragonite, and aragonitic organisms to water saturated with sodium-chloride and magnesium-sulphate, enclosed under pressure in a sealed tube, and heated for one or two days at a temperature of 90° to 100° C. The resultant action was a selective one. The calcite took up only a trace of magnesium-carbonate, aragonite absorbed 38 per cent., and corals and other aragonitic organisms over 41 per cent. The chemical instability of the aragonite was here the determining factor in the rapidity of the interchange. It is possible that, if the calcite had been exposed to the conditions of the experiment for a much longer period, the introduction of magnesium-carbonate would have proceeded farther, and probably the action would have been accelerated if the calcium-carbonate had been brought partly into solution by carbon-dioxide. The high temperature no doubt quickened the chemical changes, which probably proceed more slowly at the temperature of ordinary sea-water.

While, in general, dolomitization takes place as a result of the interchange of magnesium- for calcium-carbonate, the question arises whether it is ever deposited directly from solution. Perhaps most chemists are unfavourable to this view of its formation, and direct experiments bearing to some extent on this question have in general produced negative results. Dr. Sorby found that magnesite, and not dolomite, was formed by the action of magnesium-sulphate upon calcium-carbonate under high pressure. There is, however, mineralogical evidence in favour of the view of direct deposition of dolomite. The lining of calcite-crystals by an outer zone of clear dolomite, described by me<sup>2</sup> as occurring in sections from Mango (Fiji), and also noticed in some of the sections of Tyrol dolomite described above, is difficult of explanation, except on the hypothesis that the dolomite was deposited from solution in optical continuity with the calcite. It sometimes happens that one crystal is built up of successive zones, alternately calcite and dolomite. As these crystals are but rarely recognized in thin sections, it is clear that they were not formed under the conditions

<sup>1</sup> Tschermak's Min. & Petr. Mitth. n. s. vol. xiv (1895) pp. 531 *et seqq.*

<sup>2</sup> Bull. Mus. Comp. Zool. vol. xlii (1903) pp. 117-18.



governing the general dolomitization of the mass of the rock. It may be that they were formed in cavernous parts of the rock, more or less shut off from the free passage of the sea-water; and, indeed, these crystals are sometimes found lining the walls of cavities. Dr. C. G. Cullis, in the mineralogical report on the Funafuti boring,<sup>1</sup> describes and figures a somewhat analogous case, of the deposition of the two minerals in alternating coats lining the walls of cavities, in a way that simulates on a microscopic scale the appearance of the structure of an agate.

It would appear from this that the composition of the solution or its physical state varied from time to time, in such a way as to lead to the alternate deposition of dolomite and calcite. Possibly, in these restricted areas, the sea-water becomes saturated with calcite and the double carbonate in turn, and the conditions of equilibrium may resemble those investigated by Prof. Van 't Hoff and others in connection with the Stassfurt salts and similar deposits. Besides this peculiar and local formation of dolomite by direct deposition from solution, in the Tyrol we have to consider two other modes of occurrence of dolomite in some way resembling that just described. Some of the St. Cassian Limestones which immediately underlie the massive Schlern Dolomite of the Sella and Sett Sass, for example, contain in general only a small amount of magnesium-carbonate and usually show no visible dolomite.

In both these areas, however, microscopical examination shows that in places certain parts of the groundmass of the rock contain very minute dolomite-crystals. These are generally confined to the neighbourhood of some crack in the rock. No doubt, in this case, carbonated water, passing through the Schlern Dolomite above, dissolved some magnesium-carbonate, and, traversing the cracks in the St. Cassian Limestone below, deposited its magnesium-carbonate as small crystals of dolomite. Occasionally, these minute crystals are zoned with layers of calcite, and in one case with the isomorphous carbonate chalybite.

In the Raibl Beds overlying the Schlern Dolomite local dolomites are found, and these are sometimes intimately associated with beds of gypsum, in such a way as to leave little doubt that movements of upheaval during the Raibl period led to the enclosure of limited areas or lagoons, and caused the concentration of the sea-water and deposition of the calcium as gypsum and the magnesium as dolomite.

We have then, within the area of Southern Tyrol, to deal both with local and regional dolomitization. The mode of occurrence of some of the dolomites of the Raibl Beds, and the very partial and local dolomitization of the St. Cassian Limestones, makes it easy to suggest a probable explanation of their origin. The great problem of the origin of the Schlern Dolomite is, as has been seen, a more complex one, and a complete solution of all the difficulties will only be found when the chemical problems involved have been more fully investigated.

<sup>1</sup> Roy. Soc. (1904) p. 410 & fig. 44.

## VIII. SUMMARY OF CONCLUSIONS.

1. Recent work on modern coral-reefs has extended our knowledge as to the chemical composition of the rocks of which they are built up, especially as to the general absence of insoluble residue in the limestones.

2. The study of the relative proportions of the organisms composing coral-reefs and the alterations which they undergo has shown that corals generally play a subordinate part, and that calcareous algæ, foraminifera, and other organisms form the bulk of the rocks composing the reefs.

I have applied this information in the examination of collections from the much-debated area of the Dolomites of Southern Tyrol.

3. I find that many of the dolomites are devoid of insoluble residue, and that where residue is present it can be generally attributed, as in the raised reefs of Fiji, etc., to association with contemporaneous volcanic rocks.

4. Examination of thin sections of the rocks shows that the limestones have undergone mineralogical and chemical changes similar to those which have affected the limestones of modern reefs, and that similar organisms are represented in the Tyrol Dolomites, allowing for the loss of structure due to more complete dolomitization.

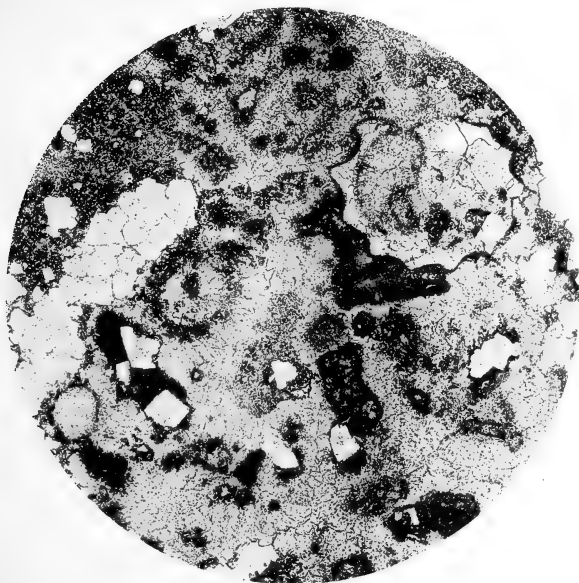
5. That the Schlern Dolomite of Southern Tyrol probably represents Triassic 'coral-reefs,' using the term in the modern, more extended sense.

6. With regard to the origin of the dolomite-masses, it is shown that the general conditions favourable to their formation were :—

- (a) Shallow water between 0 and 150 feet in depth, and corresponding to a pressure of 1 to 5 atmospheres.
- (b) The presence of carbon-dioxide in comparative abundance, causing the partial solution of the limestones and the possibility of chemical interchange with the magnesium-salts in sea-water.
- (c) Porosity of the limestones, allowing of the percolation of sea-water through the mass of the rocks.
- (d) Sufficiently-slow subsidence or elevation to render the change from calcite to dolomite complete.

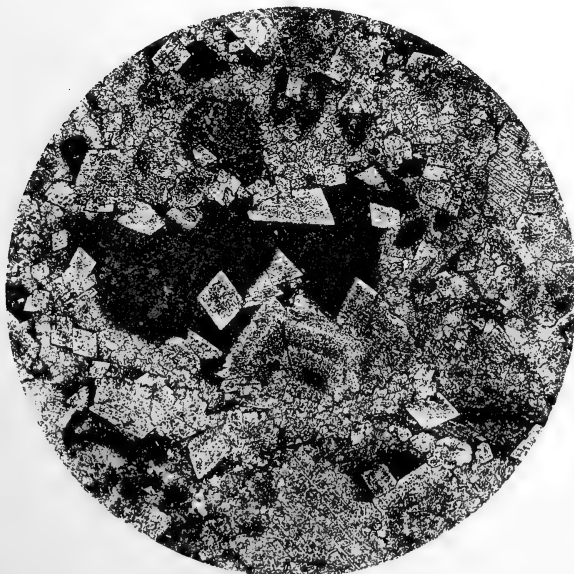
7. Locally, dolomite is deposited directly from solution in confined areas or cavities in the rock, while some of the Raibl Dolomite associated with gypsum was formed by the concentration of sea-water in land-locked areas.

FIG. 1.  $\times 11$  DIAM.



No. 100

FIG. 2.  $\times 32$  DIAM.



No. 32.

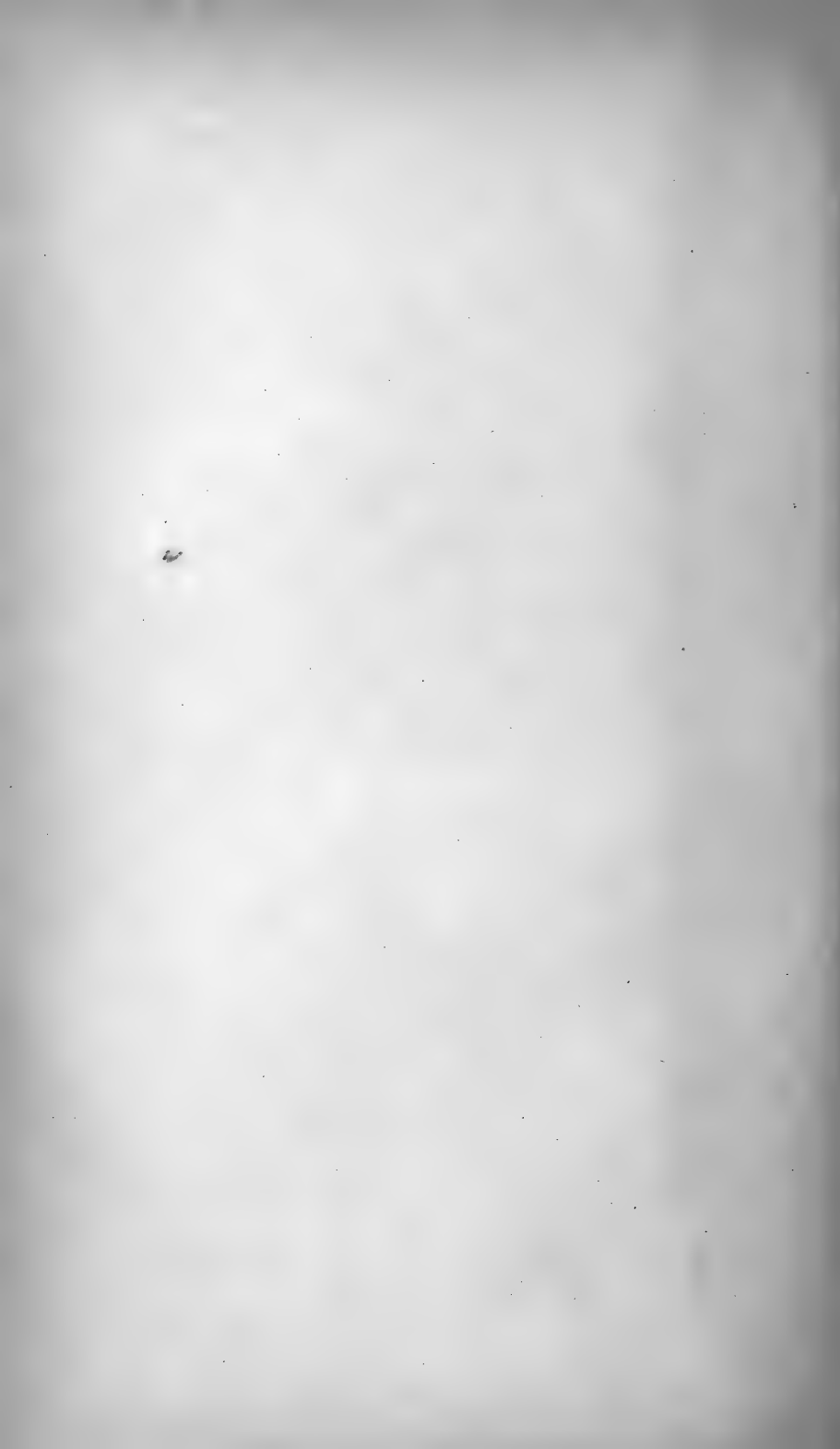
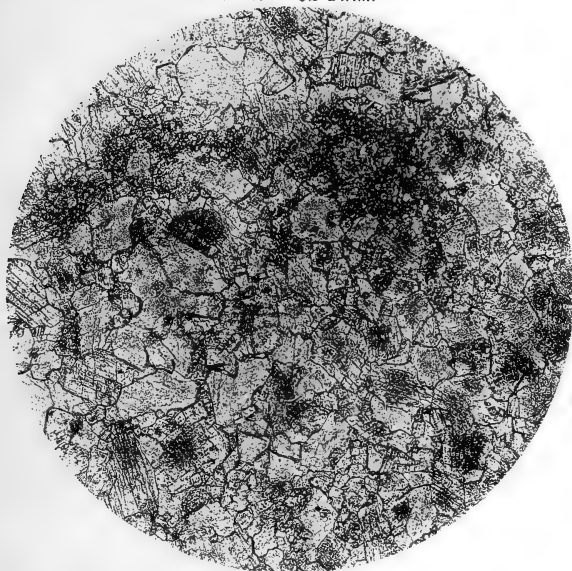
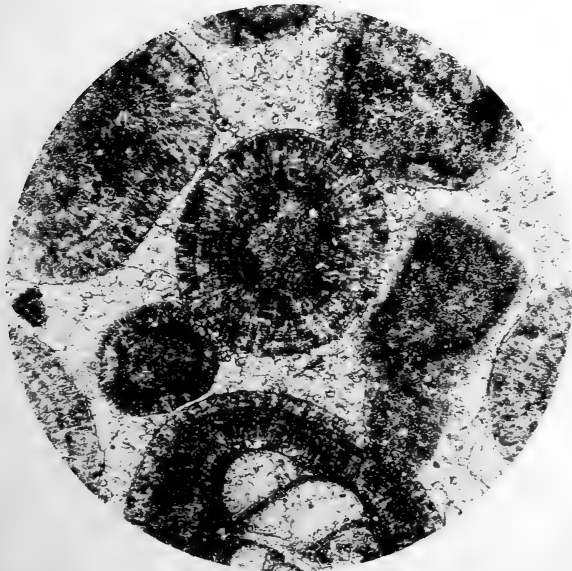


FIG. 1.  $\times 32$  DIAM.



No. 10.

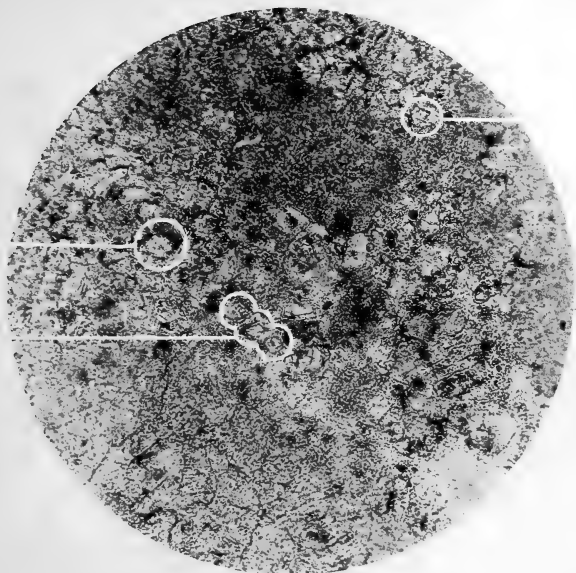
FIG. 2.  $\times 50$  DIAM.



No. 77.

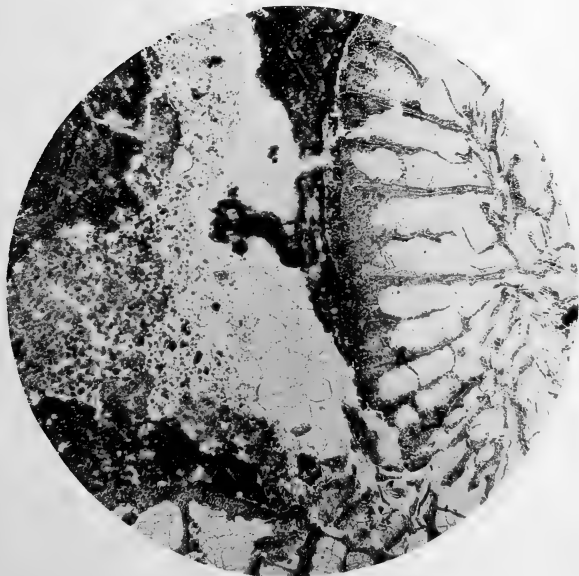


FIG. 1.  $\times 230$  DIAM.



No. 88.

FIG. 2.  $\times 18$  DIAM.



No 109.



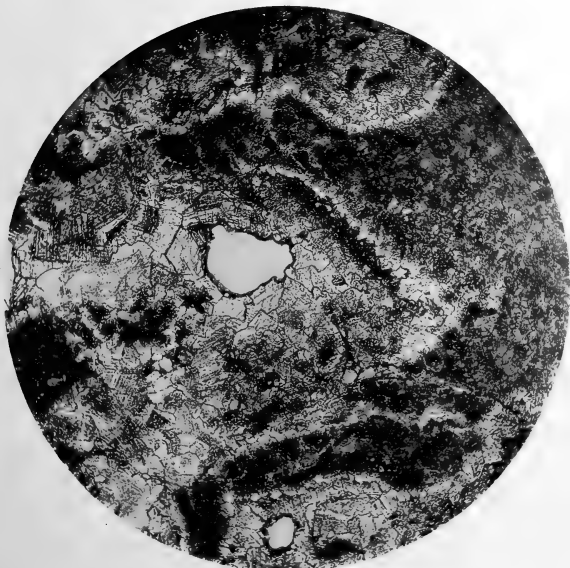


FIG. 1.  $\times 240$  DIAM.



No. 109.

FIG. 2.  $\times 30$  DIAM.



No B.

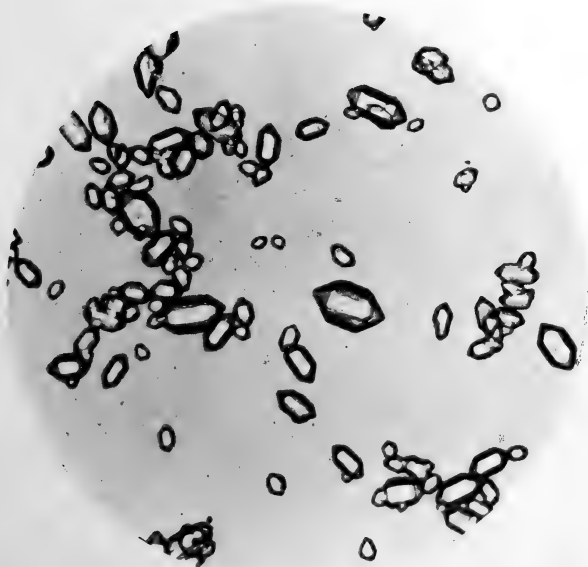


FIG. 1.  $\times 11$  DIAM.



No. 112.

FIG. 2.  $\times 250$  DIAM.



No. 37.



## EXPLANATION OF PLATES X-XIV.

[The rock-sections are preserved in the Author's private collection, but numbered hand-specimens of the rocks from the Dolomites have been deposited at the British Museum (Natural History). The Author is indebted to his friend, Mr. Franklin T. Barrett, for the photographs from which these Plates have been prepared.]

## PLATE X.

- Fig. 1. Slightly-dolomitized limestone (No. 100), from the Sella.  $\times 11$  diam. Sporadic rhombohedra of dolomite are scattered through the rock, which contains badly-preserved calcareous algæ, foraminifera, and other organisms. (Stained with Lemberg's solution.)
2. Dolomitized limestone (No. 32) from the Marmolata.  $\times 32$  diam. Some of the dolomite-crystals are allotriomorphic; but those projecting into calcite are well-formed, and show cloudy zones. (Stained with Lemberg's solution.)

## PLATE XI.

- Fig. 1. Dolomite (No. 10), from the Schlern.  $\times 32$  diam. Dolomitization is so nearly complete that no calcite remains, and the large majority of the dolomite-crystals are allotriomorphic. A few crystals with cloudy centres exhibit, however, rhombohedral outlines.
2. Oolitic and partly-dolomitized St. Cassian Limestone (No. 77) from St. Cassian.  $\times 50$  diam. The oolitic grains are well-preserved, show both concentric and radiating structure, and include foraminifera and fragments of other organisms. Minute rhombohedra of dolomite occur in the calcite-matrix, but do not extend into the oolitic grains.

## PLATE XII.

- Fig. 1. Buchenstein Limestone (No. 88), from the Gader Gorge.  $\times 230$  diam. A limestone containing zoned crystals, consisting of calcite and dolomite in alternate layers, which are in crystallographic continuity. The calcite-layers are stained with Lemberg's solution, and appear dark in the illustration.
2. Transverse section of a coral (No. 109), from the St. Cassian Limestone of Sett Sass.  $\times 18$  diam. The original aragonite and the minute structure of the coral remain. The stages in the conversion of calcareous mud into clear crystalline calcite are also shown. To this change the preservation of the coral is probably to be attributed.

## PLATE XIII.

- Fig. 1. Part of No. 109, more highly magnified.  $\times 240$  diam. The middle line of the septa is shown, as also prismatic crystals of secondary aragonite, formed in crystallographic continuity with the coral-fibres, which project from the walls of the coral into the space between the septa.
2. Dolomite ( $\beta$ ), from the stream at Bad Ratzes.  $\times 30$  diam. The dark areas probably represent septa of a coral, the structure of which has been largely destroyed by dolomitization. The lighter dolomite-crystals in the matrix show cloudy zones.

## PLATE XIV.

- Fig. 1. No. 112. Schlern Dolomite of Sett Sass.  $\times 11$  diam. Transverse section of organisms (*Gyroporella*?), the structure of which has been destroyed by dolomitization. The dark crystals defining the outer margin of the organisms have originated by the extrusion of impurities during the process of recrystallization.
2. Insoluble residue from partly-dolomitized coral (No. 37), from the Giau Pass.  $\times 250$  diam. The insoluble residue consists entirely of very minute, doubly-terminated crystals of quartz, showing occasional distortion and striation on the prism-faces.

## DISCUSSION.

The PRESIDENT said he felt that the Fellows, after listening to the Author's presentation of the work which he had done in great detail in the Tyrol and also in the laboratory, would agree that the Council had made a wise choice when they had made the first award of the Daniel-Pidgeon Fund, 'to be used in whatever way may in their opinion best promote geological original research,' to the Author.

Prof. JUDD congratulated the Society upon the valuable results secured by the first award of the Daniel-Pidgeon Fund, and at the same time complimented the Author on the lucid and effective manner in which he had marshalled his facts and arguments. He bore testimony to the great skill and patience with which the investigation had been carried out. He further ventured to express the hope, that the founder of this Fund would feel satisfied as to the success of the means which she had adopted to carry out the wishes and perpetuate the memory of her late husband. With respect to the arguments of the Author, he pointed out that the very important conclusion, that coral-rocks yield only minute traces of insoluble residue, was established not only by the Author's own analyses, but by those of several other chemists, including Mr. Stanley Gardiner. That other calcareous sediments contain a sensible proportion—1, 2, 3, or more per cent.—of insoluble residue is proved by the analyses of the *Challenger*-materials and many investigations of later date. The Author, by an application of the method described in the Funafuti Report to the classic dolomite-district of the Tyrol, had given a confirmation of the value to geologists of this crucial test concerning the origin of limestones. In addition, he had supplied a number of observations bearing on the very difficult chemical problem of dolomitization, which could scarcely fail to be of service in its ultimate solution.

Dr. E. F. ARMSTRONG remarked that, in the course of Prof. Van't Hoff's Stassfurt investigations, with which he had been associated, the problem arose as to the order in which salts would separate out from sea-water. It was a question whether dolomite existed as a true chemical compound, or was merely an intimate mixture of magnesium- and calcium-carbonates. In view of the great number of double salts known to exist, the former hypothesis seemed at least plausible. So much being granted, the problem next arose as to the conditions which governed the separation of dolomite from solution. Here, perhaps, pressure was a more important factor than any other variation that could be suggested. The Author had drawn attention to material containing a small percentage of magnesium-carbonate, but showing no evidence of dolomitization. One explanation might be that, owing to some variation in pressure, or other causes, not dolomite but magnesium-carbonate pure and simple had been deposited from solution; and it would be interesting to know whether this could be distinguished by microscopic methods from calcium-carbonate. It was noticeable, in this connection, that the uppermost rocks in the Funafuti borings, where

the pressure was consequently lowest, yielded the smallest percentage of dolomite.

Dr. C. G. CULLIS said that it was very satisfactory to find that the Author's investigations had led him to conclusions which were, in the main, harmonious with those already arrived at, along other lines of evidence, by such eminent geologists as Baron F. von Richthofen and Dr. E. von Mojsisovics, namely, that these great limestone-masses of Southern Tyrol represent the denuded remains of Triassic atolls and coral-reefs, and that the peculiar lithological characters of the rocks, as well as the distinctive physical features of the region, were merely expressions of this fact. The Author had been led to this conclusion by observing the great similarity which the rocks presented, in their chemical composition and detailed microscopic characters, to those which enter into the constitution of recent coral-reefs. From what he himself had seen of the microscopic character of coral-reef rocks, as exemplified by the cores of the Funafuti boring, he was glad to be able to confirm this resemblance, which in many cases is so striking as to make it almost impossible to avoid the conclusion that, notwithstanding their great difference in age, the two sets of rocks must have come into existence under substantially the same conditions.

Referring to the explanation of dolomitization, in terms of the relative solubility of calcium- and magnesium-carbonates under varying pressures, which the Author had suggested, he hoped that this would secure the favour and support of chemists. Speaking from recollection, he could not recall any fact or phenomenon presented by the dolomitization of the Funafuti rocks which did not find a satisfactory interpretation in the light of this simple but ingenious explanation. It seemed to him to provide the key to a problem which had puzzled geologists since the days of Leopold von Buch.

Mr. DIXON referred to the evidence that some dolomite in the Carboniferous Limestone of Pembrokeshire and Caermarthenshire is associated with shallow-water conditions.

Prof. WATTS drew attention to the probably shallow-water dolomites near Charnwood Forest, and to the base of the Carboniferous Limestone in Ireland, frequently either a dolomite, or a conglomerate or grit cemented by dolomite. He further pointed out that, although the Author had made an extremely-important comparison between the dolomites of Southern Tyrol and coral-limestones, and had shown that both of them lacked insoluble residue (which was a common ingredient in calcareous deposits), the comparison could not be followed to its logical conclusion until other calcareous sediments, such as those of the Gulf of Mexico and the Gulf-Stream areas, had been thoroughly examined.

The AUTHOR thanked the previous speakers and the Fellows present for their generous reception of his paper, and, in reply to Dr. Armstrong, stated that microscopical examination of limestones containing 10 or 12 per cent. of magnesium-carbonate failed to show the presence of magnesite as recognizable crystals.

## 9. On CERTAIN GENERA and SPECIES of LYTOCERATIDÆ.

By S. S. BUCKMAN, F.G.S. (Read December 21st, 1904.)

[PLATES XV &amp; XVI.]

## I. CERTAIN LYTOCERATIDÆ FROM THE NORTHAMPTON SANDS (AALENIAN).

SOME time ago Mr. Beeby Thompson, F.G.S., sent to me for identification certain species of *Lytoceratidæ* from the Northampton Sands. As one is new and remarkable for its homœomorphy to *Phylloceras*, and the others are interesting, I desire to offer the following notes to the Geological Society.

In order to classify the series of Toarcian-Aalenian *Lytoceratidæ*, to which these species belong (*jurensis* and allied groups), it is necessary to note that there is ontogenetic evidence that they have passed through a more or less definite sequence of phylogenetic stages. In regard to ornament, there is a sequence of development—first some elaboration, but, later, simplification from a costate (or corrugate) to a completely-smooth stage. In regard to whorl-shape, there is a constant tendency to pass, more or less in pace with the decline in ornament, from the *Lytoceratan* to the *Phylloceratan* form—that is, from an evolute to an involute whorl, the umbilicus constantly contracting. Conjointly with such change there is a further tendency, to pass from stout to constantly more compressed whorls.

Now, *Lytoceras* originally took its name from the evolute character of its whorls (*λυτός*); *Phylloceras* from the character of its lobe-line (*φύλλον*). But the whorl-character of *Phylloceras* is the opposite of *λυτός*: it is involute; and that is what is implied by saying ‘*phylloceratan whorl-shape*.’ The main difference between the *Lytoceratidæ* and the *Phylloceratidæ* may be expressed in this way: the first have the whorl-shape more primitive and the lobe-line more advanced (less of the phylloid, more of the elaborately-denticulate pattern); the second have the whorl-shape more advanced and the lobe-line more primitive (more phylloid). Consequently, when the *Lytoceratidæ* advance in regard to whorl-shape to the *Phylloceratan* style, they become characterized by an advanced whorl-shape and an advanced lobe-line. The whorl-shape being, then, similar to that of the *Phylloceratidæ*, there is a certain external homœomorphy; but the more advanced lobe-line remains a feature of distinction, showing that a given species belongs to the *Lytoceratan* stock, however much it may simulate the *Phylloceratan* shape.

It may be desirable to explain that, in speaking of the *λυτός*-character as primitive, I refer only to that portion of the Cephalopod-



cycle to which the *Lytocerata* belong. The whole Cephalopod-cycle is from straight to coiled up (involute) and back to straight again; but within this main cycle are found many subsidiary cycles, of successive retreat and advance, from involute to evolute, on again to involute, and so on. Through the phases of one of such subsidiary cycles the *Lytocerata* pass. Like the *Ammonacea*, they have evidently come through an involute, *Goniatic*, stage; they revert to the evolute stage, and advance again towards involution—the evolute is therefore more primitive than the later involute. However, in reverting towards evolution and the *Orthoceratan* style, the *Lytoceratidæ* went much farther than the *Phylloceratidæ*, and they retain the evolute character longer. Then, changing this process, going again towards involution, the *Phylloceratidæ* begin first, at a time when their lobe-line is still more primitive than that of the *Lytoceratidæ*. The latter, starting later on the same way, seldom progress so far towards involution as the former; but the interesting species which I have to describe is the most noticeable case of how far they do travel in that direction.

Now, in the *jurense*-groups—to one of which this species belongs—the development in regard to ornament presents, more or less completely, these stages:—subcostate, costate (crassicostate, or corrugate), returning to subcostate, and levigate. But the development of the phyletic series does not end here. The levigate character is attained while the species are somewhat evolute; it is retained while they become (in one case) truly involute (*Phylloceratan*). These successive stages of development may be indicated in terms of species:—(1) *Germaini*, (2) *torulosum*, (3) annulose, the species not yet named,<sup>1</sup> (4) *jurense*, (5) *phylloceratoidan*; and the species mentioned are adults, more or less in these respective stages of development.

That the species like *jurense* were levigate developments of *Germaini*-like forms I have pointed out before.<sup>2</sup> But a cursory examination of these species shows that they belong to more than one genetic series, that the smooth forms are polygenetic, and have passed through independent costate stages. Two of such genetic series Hyatt has separated as genera: *Pleurolytoceras*, the *hircinum*-group; *Alocolytoceras*, the *Germaini*-group.<sup>3</sup> To neither of these can the *torulosum*-group be fitted. Although *torulosum* shows that it came through a *Germaini*-like stage, yet its corrugate stage differs from that of the *Germaini* series, and its levigate developments differ from those of that series also. It seems, therefore, necessary

<sup>1</sup> *Lytoceras Germaini*, Janensch (*non* d'Orbigny), Abh. z. Geol. Specialk. von Elsass-Lothringen, n. s. pt. v (1902) pl. ii, fig. 3 only, shows this stage. Compare also *Lytoceras dilucidum* (Oppel), Pompeckj.

<sup>2</sup> 'The Reported Occurrence of *Ammonites jurensis* in the Northampton Sands' Geol. Mag. 1892, p. 260. Dr. J. F. Pompeckj also has given much information concerning the development of these forms, in his 'Beiträge zu einer Revision der Ammoniten des Schwäbischen Jura' pt. ii (1896) pp. 95 *et seqq.*

<sup>3</sup> Eastman-Zittel, 'Text-book of Palæontology' vol. i (1900) p. 572.

to give to *torulosum* and its smooth derivatives a new generic designation; and the three genera may be compared as follows:—

**PLEUROLYTOCERAS**, Hyatt. Characterized by peripheral compression making the whorl-section triangular, which character is developed even in the costate stage.

Species:—Stage 1. *A. hircinus* (Schlotheim) (Quenstedt).

Stage 2. *A. Leckenbyi*, Lycett; *A. hircicornis*, Schloenbach.

Apparently this series does not progress to the further (levigate) stage.

**ALOCOLYTOCERAS**, Hyatt. Peripheral compression slight; whorls passing from round to oval, to elliptical in the costate stage, to compressed elliptical in the smooth stage.

Species:—Stage 1. *Lytoceras coarctatum*, Pompeckj; *A. Germani*, d'Orbigny. Stage 2? *Al. Pompeckji*, nom. nov. (see below, p. 145). Stage 3. *Lytoceras dilucidum* (Oppel), Pompeckj. Stage 4. *Lytoceras sigaloei*, S. Buckm.; *L. Wrighti*, S. Buckm.; *L. tæniatum*, Pompeckj (Stages 2, 3, in inner whorls).

**PACHYLITOCERAS**, gen. nov. (*torulosum*-group).<sup>1</sup> No triangularity, no peripheral compression; but, rather, whorls somewhat inflated towards the periphery. Whorls round in the costate stage, to stout oval in the levigate. Genotype, *A. torulosus*, Zieten.

Species:—Stages 1, 2. *A. torulosus*, Zieten. Stage 4. *A. jurensis*, Zieten; *P. aalenianum*, sp. nov., with stage 2 in inner whorls (see below, p. 146). Stage 5. *P. phylloceratoides*, sp. nov. (see below, p. 147).

So there are, in these genetic series, as morphic equivalents distinguished by their whorl-shape: in Stage 1, *Pl. hircinum*, *Al. Germani*, *P. torulosum* (young); in Stage 2, *Pl. Leckenbyi*, *P. torulosum* (adult); in Stage 4, *Al. sigaloei*, *Al. Wrighti*, and *P. jurensis*, *P. aalenianum*, respectively; while in Stage 5 there is no morphic equivalent to *P. phylloceratoides*. Stage 2, or the corrugate stage, seems to be particularly well-developed in two series, and the contrast between *Pleurolytoceras Leckenbyi* and *Pachylytoceras torulosum* is especially marked; but in *Alocolytoceras* this stage does not seem to be developed in a noticeable manner—the species presumably to be reckoned to it is *Al. Pompeckji*. If there is this difference in development, it will be a still more important distinction between *Alocolytoceras* and *Pachylytoceras*.

In these genera the lobe-lines are of very similar pattern: the saddles retain much of the primitive phylloid character, the lobes are wide-stemmed, and not spreading, while they lack the high development of the typical *Lytoceras*-lobes. For further remarks on these lobes, see p. 151.

<sup>1</sup> Πάχυς, stout.

The following are the notices of Mr. Thompson's species, with remarks on certain allied forms to which consideration has to be given.

*ALOCOLYTOCERAS GERMAINI* (d'Orbigny). (Fig. 3, p. 152.)

1845. *Ammonites Germaini*, d'Orbigny, 'Pal. Franç. Terr. Jur.: Céphalopodes' p. 320 & pl. ci, figs. 4-5 only.

Dr. Pompeckj<sup>1</sup> chooses the form above-quoted to be the type of d'Orbigny's species, and therefore it is necessary to follow him. But I cannot agree with him, that what he figures as the smooth form of this species, really belongs to it (*op. cit.* fig. 27, p. 145). It is a smooth form, which has the inner whorls of the *Germaini*-stage certainly; but, surely, it is of another stock altogether: the long lobes and the broad inner margin of the stout whorls are characters which, in my opinion, separate it from any of the three genetic series now under consideration.

*ALOCOLYTOCERAS POMPECKJI*, nom. nov.

1845. *Ammonites Germaini*, d'Orbigny, 'Pal. Franç. Terr. Jur.: Céphalopodes' p. 320 & pl. ci, figs. 1-2 (not 4-5, and not 6).

Description.—Dr. Pompeckj described this form as follows:—

'*Lytoceras*, n. sp. Rarer than the preceding species [*Germaini*], with higher whorls, with more oval cross-section and more closely-set ribs.' (*Op. cit.* p. 146.)

Remarks.—Although Dr. Pompeckj separated this form, he did not name it, and so I have much pleasure in dedicating it to him, as a mark of appreciation of the value of his critical studies, particularly in regard to his revision of Quenstedt's last work.

*ALOCOLYTOCERAS DILUCIDUM* (Oppel).

In naming his species, Oppel gave as a synonym a term of Quenstedt's, which that author had applied as the designation for '*A. cornucopiæ* d'Orbigny tab. 99.' Quenstedt did not quote any figure of d'Orbigny's plate, and therefore I presumed that he meant figs. 1 & 2;<sup>2</sup> but Dr. Pompeckj has now figured one of Oppel's types,<sup>3</sup> from which it is evident that Oppel and Quenstedt intended d'Orbigny's pl. xcix, fig. 4.

The question now is, what must be taken as the holotype of Oppel's species? It seems to me that, as Oppel gave a definite reference which led to d'Orbigny's pl. xcix, one of the species thereon must be the holotype. As it is now seen that fig. 4 was intended, therefore that must be the holotype. Oppel's other examples must be regarded as paratypes; and it does not necessarily follow that they belong to the same species as the holotype—that is far too often the result in such cases. The original references, therefore, would be:—*Al. dilucidum* (Oppel): Description—'Die

<sup>1</sup> 'Beiträge zu einer Revision der Ammoniten des Schwäbischen Jura' pt. ii (1896) p. 146.

<sup>2</sup> '*Ammonites jurensis*,' Geol. Mag. 1892, p. 260.

<sup>3</sup> 'Beitr. Rev. d. Amm. d. Schwäb. Jura' pt. ii (1896) p. 166 & pl. xii, fig. 8.

Juraformation' (1856) p. 372; figure of holotype—d'Orbigny, 'Pal. Franç. Terr. Jur.: Céph.' (1845) pl. xcix, fig. 4 only.

*ALOCOLYTOCERAS TÆNIATUM* (Pompeckj), 1896. (Pl. XVI, figs. 1–2, & text-fig. 6, p. 152.)

1896. *Lytoceras tæniatum*, Pompeckj, 'Beiträge zu einer Revision der Ammoniten des Schwäbischen Jura' pt. ii, p. 164 & pl. xii, fig. 7.

= ? *Lytoceras Wrighti*, S. Buckman, 1888, 'Monogr. Inf. Ool. Amm.' (Pal. Soc.) pt. ii, p. 44, footnote 2.<sup>1</sup>

Remarks.—The specimen submitted by Mr. Thompson agrees with the above-quoted figure of Dr. Pompeckj's species, so far as comparison can be made; but the example is deficient in the umbilical whorls. The Northampton specimen shows, in the umbilicus of the side not depicted in the Plate, striæ indicative of the annulose stage; Dr. Pompeckj's figure shows both this and the *Germaini*-stage. But the Northampton specimen does not differ in shape from my *Lytoceras Wrighti*. Is, therefore, Pompeckj's species the same as mine? or is it a case of homœomorphy? So far, these characters of the *Germaini* and annulose stages have not been noted in my species. The specimens are large, and the inner whorls seem to be particularly smooth.

Dr. Pompeckj (*op. cit.* p. 171) has misread the position of *Al. Wrighti* in the genetic series, when he thinks that it may be the same as his *Lytoceras dilucidum*; my *L. sigalœn* is the species which occupies that position, so that the comparable species in the same stage of development are *L. dilucidum*, Pomp. (? Oppel) and *L. sigalœn*; *L. tæniatum*, Pompeckj, and *L. Wrighti*, respectively. Now, according to Pompeckj's figures, there is considerable difference in the ontogeny of his *L. dilucidum* and *L. tæniatum*—a difference which suggests that they really belong to separate genetic series. That may be the explanation of the likeness of *L. tæniatum* and *L. Wrighti*: it may be a case of homœomorphy. To settle this, in fact, before one can dogmatize on the identity of any smooth catagenetic species, it is necessary to be well-informed concerning their ontogeny.

Locality and Horizon.—Spratton Ironstone Workings, Brixworth, near Northampton, in the Northampton Sands.

Date.—*Hemera scissi*, presumably. Ammonites of the genera *Lioceras* and *Tmetoceras* indicate that the Northampton Sands are of this date; and there is no evidence of any earlier date as yet. The date of *Al. Wrighti* is *hemera aalensis*; in strata of that hemera I have found it both in the Cotteswolds and on the Dorset coast. Dr. Pompeckj quotes *Al. tæniatum* from 'Zone of *Lyt. torulosum*, Br. Jura a Quenstedt.' (*Op. cit.* p. 166.)

*PACHYLYTOCERAS AALENIANUM*, sp. nov. (Pl. XV, figs. 3 & 4, & text-fig. 5, p. 152.)

Description.—A *Lytocera*toid like *jurense*, but with a smaller

<sup>1</sup> The type-figure is *Lytoceras jurense*, Wright (*non* Zieten), 'Monogr. Lias Amm.' (Pal. Soc.) 1884, pt. vii, pl. lxxix.

umbilicus. Inner whorls subcostate, showing the *torulosum*-stage; outer whorl smooth, stoutly oval. Inclusion about two-thirds. Umbilicus gradate.

Distinction.—From *P. jurense*, a smaller umbilicus, broader whorls, greater inclusion.

Remarks.—The inner whorl, showing the *torulosum*-stage, is a most interesting fact in the ontogeny, important for indicating genetic affinity. Such an inner whorl is the morphic representation of *P. torulosum*.

Locality and Horizon.—Spratton Ironstone Workings, Brixworth, near Northampton, in the Northampton Sands.

Date.—*Hemera scissi*, presumably; see under *Alcolytoceras tæniatum* (p. 146).

**PACHYLYTOCERAS PHYLLOCERATOIDES**, sp. nov. (Pl. XV, figs. 1–2 & Pl. XVI, fig. 3.)

Description.—A *Lytoceratoid* with a *phylloceratan* aspect; outer whorl stoutly oval, smooth; umbilicus quite small, umbilical border fairly steep.

Distinction.—The *parvumbilicus*, and the *phylloceratan* aspect of the fossil.

Remarks.—In the ‘Geology of the Country around Cheltenham’ (Mem. Geol. Surv. 1857), Prof. Hull notices (p. 30) ‘a large ammonite 1 ft. 8 in. in diameter,’ which, he says, ‘strongly resembles *A. heterophyllus*,’ in Sands [*scissum*-beds] at Clapton, near Sherborne (Gloucestershire). I suggest that it is a *parvumbilicate* *Lytoceratoid* closely allied to, or the same species as, the one now under consideration. I do so, because some 20 years ago I saw in the possession of the late Dr. Moore, at Bourton-on-the-Water, several giant *parvumbilicate* *Lytoceratoids* which had been obtained, during the making of the Banbury & Cheltenham Railway, from the first cutting on the west, presumably from the Sands. That they were *Lytoceratoids* with *phylloceratan* aspect attracted my attention at the time.

From Dorset I have long had a similar large *parvumbilicate* form; but I fancy that it is not the same species as Mr. Thompson’s. I cannot examine it now.

Locality and Horizon.—Spratton Ironstone Workings, Brixworth, near Northampton, in the Northampton Sands.

Date.—*Hemera scissi*, presumably. See note to *Al. tæniatum*.

## II. OTHER GROUPS OF JURASSIC LYTCERATIDÆ.

In connection with the *Lytoceratidæ* which have been reviewed, it seems desirable to note certain new or incompletely-known genera of this family. It is important for all systematic work to give to each genetic series (or *Formenreihe*) its own generic name. For museum-work, for cataloguing, for classification, and for ready identification, the more this system is tried the better does it

prove, and the more completely does it show the true genetic affinities. The American palæontologists have proved these statements in regard to the Palæozoic Brachiopoda. To use a generic term in a wide sense, and then to group the species under their respective *Formenreihe* is hardly satisfactory: the formula is much longer and more difficult to remember than a generic name. Therefore, after noting some already-established generic names, I venture to propose certain generic appellations for other genetic series, with the species of which we are more particularly concerned in our British Jurassic rocks.

#### Genus *LYTOCERAS*, Suess, 1865.

Genotype, *Ammonites fimbriatus*, Sowerby.

1865. E. Suess, 'Ueber Ammoniten' Sitzungsberichte d. nat.-wiss. Classe d. k. Akad. d. Wissensch. Wien, vol. lii, p. 78.

Another species, *Lytoceras lineatum*, Wright (*non* Schlotheim?), 'Monogr. Lias Amm.' (Pal. Soc.) pl. lxix, fig. 1, 1882, & p. 409, 1883.

#### Genus *THYSANOCERAS*, Hyatt, 1867.

Genotype, *Ammonites cornucopia*, d'Orbigny (*non* Young)  
= *Thysanoceras Orbignyi*, nom. nov.

1867. *Thysanoceras*, Hyatt, Bull. Mus. Comp. Zool. vol. i, pp. 86, 96.

Remarks.—Hyatt selected no genotype. The first species that he mentions is *Ammonites fimbriatus*; but this had just before been taken by Suess as his type of *Lytoceras*. In *Thysanoceras*, however, Hyatt placed many other *Lytoceratoid* species; and, as it is now necessary to divide them into genera, it seems permissible to take as the type of *Thysanoceras* a species most allied to *Am. fimbriatus*. Therefore I select *Am. cornucopia*; but, under this name, Hyatt included the species of Young and of d'Orbigny. They are two distinct species: as the latter is far the better illustrated, I select that as the type of the genus; it will require a new name.

*Thysanoceras*, then, will be the name for the genetic series of *Am. cornucopia*, d'Orbigny; *Lytoceras* for that of *Am. fimbriatus*. The two genera differ particularly in their shell-sculpture; and also that in *Lytoceras* the periodic 'flares' are plain and prominent, but in *Thysanoceras* they are crenulate and not prominent.

These two genera attain to a high degree of development in their suture-lines,<sup>1</sup> differing in that respect markedly from any of the genera of the *jurense*-groups (*Pachylytoceras* and like genera; see above, p. 144): those still retain the phylloid saddles, indicative of the original common ancestry of *Lytoceratidæ* and *Phylloceratidæ*; these have practically lost that ancestral trait; however, they retain the primitive *λυρός*-character. They do not seem to develop smooth forms like the *jurense*-groups.

<sup>1</sup> Skeleton L, fig. 7, p. 152.

## THYSANOCERAS ORBIGNYI, nom. nov.

1845. *Ammonites cornucopia*, d'Orbigny (*non* Young), 'Pal. Franç. Terr. Jur.: Céphalopodes' p. 316 & pl. xcix, figs. 1-3 (not fig. 4).

1867. *Thysanoceras cornucopia*, Hyatt, Bull. Mus. Comp. Zool. vol. i, p. 96 (*pars*).

Remarks.—The difference in coiling and the fact that the whorls are depressed, instead of being compressed, separate this species entirely from Young's. Figs. 1 & 2 are not Oppel's *dilucidus* (see *Al. dilucidum*, above, p. 145): so a new name is required. D'Orbigny's figure is reduced to  $\frac{1}{4}$ -linear according to the dimensions which he gives: he says that it is 'reduced one-half' ('réduite de moitié,' *op. cit.* p. 318).

THYSANOCERAS ONYCHOGRAPTUM,<sup>1</sup> nom. nov.

1883. *Lytoceras cornucopia*, Wright (*non* Young, *nec* d'Orb.) 'Monogr. Lias Amm.' (Pal. Soc.) pt. vi, p. 410 & pl. lxxiii, figs. 1, 2 (3?).

This species differs so entirely in its proportions from *Am. cornucopia*, Young, that a new name is necessary. The sculpturing, which is similar to the marks made by pressing a finger-nail into wet clay, suggests the term now proposed. From d'Orbigny's species it differs by less coarse sculpturing, and by a more elevated periphery, making the whorls compressed instead of depressed. In this respect it is nearer to *Am. cornucopia*, Young, than is d'Orbigny's species.

Other species are:

1. *Thys. sublineatum* (Oppel) = *Am. sublineatus*, Oppel.<sup>2</sup>
2. *Thys. cornucopia* (Young) = *Am. cornucopia*, Young, 'Geol. & Min. Surv. Yorks. Coast' (1822) pl. xii, fig. 6 = *Am. fimbriatus*, Zieten (*non* Sow.) 'Verst. Würt.' (1830) p. 16 & pl. xii, fig. 1 = *Am. Siemensi*, Denckmann, 'Fauna des oberen Lias von Dörnten' Abhandl. d. k. Preuss. Geol. Landesanst. vol. viii (1887) p. 156 & pl. i, fig. 5.

## Genus THYSANOLYTOCERAS, nov.

Genotype, *Ammonites Eudesianus*, d'Orbigny.

Definition.—A *Lytoceratoid* genus, which in suture-line most resembles *Lytoceras* (*fimbriatum*-group), in ornament follows partly *Lytoceras*, partly *Thysanoceras* (*cornucopia*-series); for the main ornament is more of the type of the former, while the crenulate 'flares' are more of the pattern of the latter, yet in these details the genus agrees with neither.

Examples.—*Thysanolytoceras* sp., a heavy stout shell of the *Eudesianum*-type, *Sonniniæ-Witchellie* hemera; Sherborne (Dorset);<sup>3</sup> = ? *Am. subamplus*, Quenstedt, 'Ammoniten des Schwäbischen Jura' vol. ii (1886-87) p. 477.

<sup>1</sup> "Ουνξ, a nail; γραπτός, written.

<sup>2</sup> 'Pal. Mitth.' pt. iii. (1862) p. 142 & pl. xliii, figs. 4-6.

<sup>3</sup> There is a giant of this species in the Cephalopod-Gallery of the Natural History (British) Museum [No. C 3184], from the Collection of Mr. Darell Stephens, now Mr. R. D. S. Darell, F.G.S.

*Am. Eudesianus*, d'Orbigny (*op. cit.* 1846, p. 386 & pl. cxxviii);  
*niortensis* hemera.

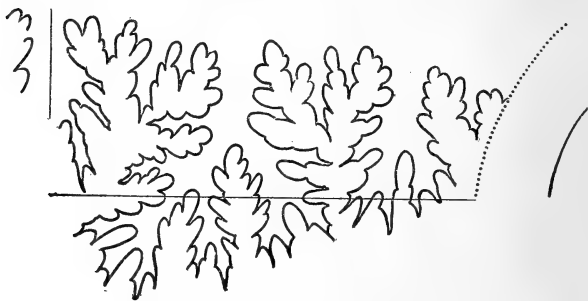
*Am. Adeloides*, Kudernatsch, 'Die Ammoniten von Swinitza'  
 Abhandl. d. k.-k. Geol. Reichsanst. vol. i (1851) Abh. 2,  
 p. 9 & pl. ii, figs. 14-16.

Genus *MEGALYTOCERAS*,<sup>1</sup> nov.

Genotype, *Lytoceras confusum*, S. Buckman.

Definition.—A genus which has much the aspect of the *jurense*-group,<sup>2</sup> smoothness being very noticeable; but it possesses an ornate suture-line, with narrow-stemmed, highly-developed lobes (see fig. 1) like *Lytoceras*, or *Thysanoceras*. Like *Lytoceras* it shows plain periodic 'flares,' but they are not associated with sculpturing, in the species at present known, and they are confined to the young stage. The development of a broadly-deltoid cross-section of whorl, and the fact that in the smooth stage the whorls are still evolute, are also important features.

Fig. 1.—Suture-line of *Megalytoceras confusum* (S. Buckman) from the type-specimen, obtained by the removal of the test; some of the finer details may have suffered in the process. (Natural size.)



*MEGALYTOCERAS CONFUSUM* (S. Buckman). (Fig. 1, & fig. 9, p. 152.)

1881. *Lytoceras confusum*, S. Buckm. 'Amm. Inf. Ool. of Dorset' Quart. Journ. Geol. Soc. vol. xxxvii, p. 601 (description).

[1883] *L. confusum*, S. Buckm. Proc. Dorset Nat. Hist. Field-Club, vol. iv, pl. iii, fig. 1 & p. 143 (fig. & descr.).

Remarks.—I give these references, because on the Continent the fact that this species is figured has been overlooked; and it has been confounded with others of more recent date. A tracing of the suture-line of the holotype is appended (fig. 1, above).

<sup>1</sup> Μέγας, large; μέγα-, for μέγαλο-: the Greeks themselves warrant this; and it is very desirable in the present case.

<sup>2</sup> The genotype obtained its name, because it had been mistaken for *P. jurense*, and had thereby caused confusion in stratal correlation.



Other species are :—

*Megalytoceras rubescens* (Dumortier) = *Am. rubescens*, Dumortier, 'Dépôts Jur. du Bassin du Rhône' pt. iv (1874) p. 114 & pl. xxix, fig. 5; & Vacek, 'Die Fauna der Oolithe von Cap S. Vigilio' Abhandl. d. k.-k. Geol. Reichsanst. vol. xii (1886) p. 63 & pl. i, fig. 5.

*Megalytoceras* sp. = *Lytoceras*, n. sp. indet., Vacek, *op. cit.* p. 64 & pl. i, figs. 6-7.

? *Megalytoceras rasile* (Vacek) = *Lytoceras rasile*, Vacek, *op. cit.* p. 63 & pl. iii, figs. 5-8.

*Megalytoceras amplum* (Oppel) = *Ammonites amplus*, Oppel, 'Pal. Mitth.' pt. iii (1862) p. 145 & pl. xlv.

#### Genus NANNOLYTOCERAS,<sup>1</sup> nov.

Genotype, *Ammonites pygmaeus*, d'Orbigny.<sup>2</sup>

Definition.—A primitive Lytoceratoid genus; whorls smooth, evolute, compressed, with distant, ill-marked periodic constrictions.

Distinction.—From *Lytoceras* and like genera by the absence of sculpturing and 'flares'; from *Pachylytoceras* and like genera by the association of smoothness with an evolute, compressed whorl. In those genera the smoothness is a catagenetic feature; in this genus all the evidence points to its being an anagenetic character—the genetic series not having passed through the ornate stages.

#### Comparison of Superior Lateral Lobes.

The accompanying figures (p. 152) show the contrasts and affinities of various superior lateral lobes (L), in skeleton outline, omitting minor details. Fig. 2 shows a supposititious normal tricoonulate lobe, with the terminal lobule, A, isosceles. Fig. 3 shows the L (outline) of *Al. Germaini* (*Pompeckji*), after d'Orbigny; and if A be rightly interpreted as the terminal lobule, then this lobule is ultra-brachysceles (short-legged on the outer part). The same feature, even more pronounced, is seen in figs. 4 & 5; and the greater development of the inner lobule (C) in proportion to the outer (B) causes the lobe to assume a bifid pattern. In all the figs. 3-6 belonging to the *jurense*-groups, the wide-stemmed character of the lobe and its want of 'spread' are noticeable—they are all of a similar plan, in marked contrast to the narrow-stemmed, wide-spread lobes depicted in figs. 7-9. In these there is the ultra-brachysceles character of A, but in figs. 8 & 9 it may be noted that B is rapidly enlarging and becoming more equal to C,—in fact B begins to usurp the functions of the siphonal lobe, see fig. 1 (p. 150). The difference between fig. 9 and figs. 4-6 shows how distinct is *Megalytoceras* from the *jurense*-groups, in spite of a somewhat similar aspect. But, if the inferior lateral lobe of *Megalytoceras* (fig. 1) be compared with the L of the *jurense*-groups (figs. 4-6), it will be

<sup>1</sup> Νάννος, a dwarf.

<sup>2</sup> 'Pal. Franç. Terr. Jur.: Céph.' 1846, p. 391 & pl. cxxix, figs. 12-13.

Figs. 2-9.—Skeletons of superior lateral lobes.

Fig. 2 = A supposititious trilobulate lobe, with an isosceles terminal lobe—the supposed norm.

3 = L of *Alcolytoceras Germaini* (*Pompeckji*), after d'Orbigny.

4 = L of *Al. sigalœn*, after d'Orbigny (*Ammonites jurensis*).

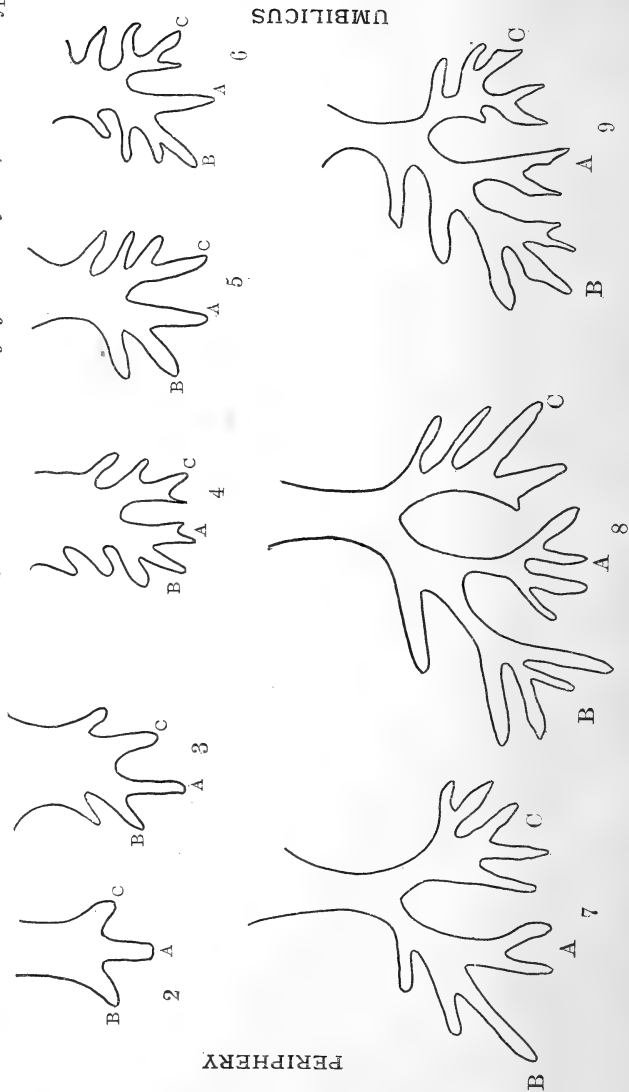
5 = L of *Pachylotoceras aalenianum*, from nature, Pl. XV, fig. 3.

Fig. 6 = L of *Alcolytoceras tenuatum*, from nature, Pl. XVI, fig. 1.

7 = L of *Lyptoceras finbrittum*, after d'Orbigny.

8 = L of *Thysanolytoceras Eudesianum*, after d'Orbigny.

9 = L of *Megalytoceras confusum*, from the holotype.



PERIPHERY

UMBILICUS

[Note: A, B, C, indicate the parts supposed to be homologous with a trilobulate lobe;  
A = terminal lobe; B = ultra-lobe; C = intra-lobe.]

seen to have a similar pattern—that is, a lobe of later phylogenetic origin in a more highly-developed lobe-line is similar to a lobe (L) of earlier origin in a less-developed line. While the L of *Megalytoceras* has passed far beyond the L of the *jurensis*-groups, the *l* (the lobe of later origin) of the first has come up to about the same stage as the L of the second.

This observation somewhat confirms those of R. T. Jackson,<sup>1</sup> with a difference. He noted that a law of progressive and successive development, a kind of ontogenetic repetition of phylogeny, applied to the elaboration of any parts of an individual as much as to the whole; and he adduced as instances the individual lobes of the same specimen during ontogeny, and the various lobes and lobules of the same suture-line. In the present case, there appears to be a similar law of development in the lobes of different stocks considered as parts of a family, the stocks having elaborated their suture-lines to different degrees of development. In the case of two stocks, one of which has carried the development of its suture-line much farther than the other, the less-developed lobe of the most-developed stock is found to be similar to the most-developed lobe of the less-developed one.

### III. SUMMARY.

#### New Genera.

<b>Pachylytoceras,</b>	Genotype <i>Ammonites torulosus</i> , Zieten.
<b>Thysanolytoceras,</b>	„ <i>Am. Eudesianus</i> , d'Orb.
<b>Megalytoceras,</b>	„ <i>Lytoceras confusum</i> , S. Buckm.
<b>Nannolytoceras,</b>	„ <i>Ammonites pygmaeus</i> , d'Orb.

#### New Species.

<b>Pachylytoceras aalenianum,</b>	Aalenian.
„ <b>phylloceratoides,</b>	„

#### New Names.

<i>Alocolytoceras</i> <b>Pompeckji</b>	for <i>Ammonites Germaini</i> , d'Orb. pl. ci, figs. 1 & 2.
<i>Thysanoceras</i> <b>Orbigny</b>	for <i>Am. cornucopia</i> , d'Orb. (non Young), pl. xcix, figs. 1–3.
<i>Thysanoceras</i> <b>onychograptum</b>	for <i>Am. cornucopia</i> , Wright (non Young).

#### Generic name revised.

<i>Thysanoceras</i> , Hyatt. Type selected, <i>Am. cornucopia</i> , d'Orb. = <i>Th. Orbigny</i> , nov.
---

#### Species figured.

<i>Alocolytoceras tæniatum</i> (Pompeckj).
<b>Pachylytoceras aalenianum</b> , nov.
„ <b>phylloceratoides</b> , nov.
<i>Megalytoceras confusum</i> (S. Buckm.), lobe-line of.

<sup>1</sup> 'Localized Stages in Development in Plants & Animals' Mem. Boston Soc. Nat. Hist. vol. v, No. 4 (1899) pp. 134 *et seqq.*

EXPLANATION OF PLATES XV & XVI.

[All the figures are of the natural size.]

PLATE XV.

Northampton Sands, Aalenian [*Hemera scissi*].

Figs. 1 & 2. *Pachylitoceras phylloceratoides*, sp. nov. Spratton Ironstone Workings, Brixworth, near Northampton. Collection of Mr. Beeby Thompson, F.G.S. Fig. 1. Side-view. 2. Section of whorl at A (restored) outline.

Figs. 3 & 4. *Pachylitoceras aalenianum*, sp. nov. Spratton Ironstone Workings, Brixworth, near Northampton. Collection of Northampton Museum. Fig. 3. Side-view: inner whorl showing *torulosum*-stage. Fig. 4. End-view.

PLATE XVI.

Northampton Sands, Aalenian [*Hemera scissi*].

Figs. 1 & 2. *Alocolitoceras tæniatum* (Pompeckj). Same locality and collection as *P. aalenianum*. Fig. 1. Side-view. 2. End-view.

Fig. 3. *Pachylitoceras phylloceratoides*. Peripheral view, in outline (restored).

[For the excellent photographs from which these Plates have been reproduced, my cordial thanks are due to my friend Mr. J. W. Tutchter, who happily combines great photographic skill with extensive geological knowledge.]



FIG. 1.



FIG. 3.

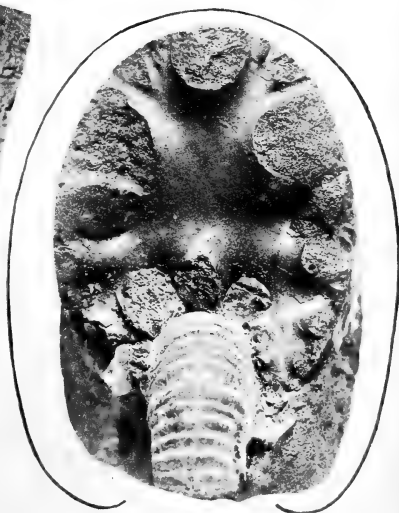


FIG. 4.

PACHYLYTOCERAS PHYLLOCERATOIDES AND P. AALENIANUM.



FIG. 1.



FIG. 3.



FIG. 2

ALOCOLYTOCERAS TÆNIATUM AND PACHYLYTOCERAS  
PHYLLOCERATOIDES.





10. *The TERTIARY FOSSILS of SOMALILAND, as represented in the BRITISH MUSEUM (NATURAL HISTORY).* By RICHARD BULLEN NEWTON, F.G.S. (Read June 22nd, 1904.)

## [PLATES XVII-XXI.]

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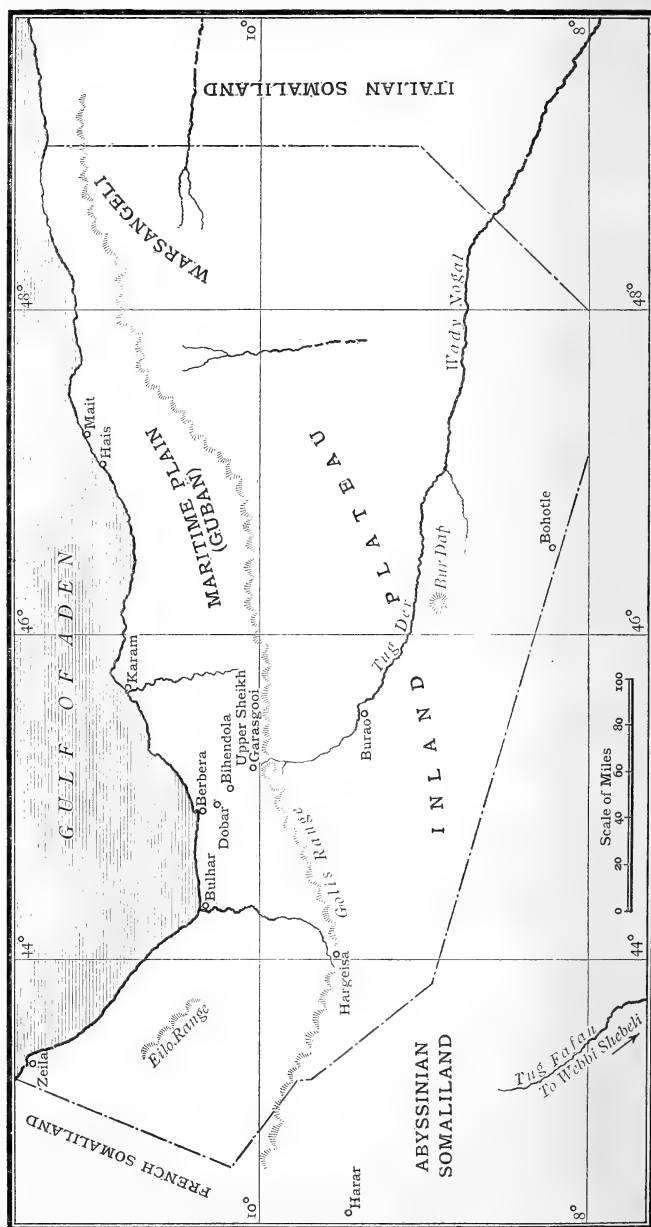
## I. INTRODUCTION.

SINCE the publication in the fifty-sixth volume of this Journal (1900) of Prof. J. W. Gregory's paper on the Geology of Somaliland, which was founded upon specimens in the British Museum (Natural History) mostly collected and presented by Mrs. Lort-Phillips, the National Collections have been enriched by two further series of fossils from the same country—that obtained by Dr. Donaldson Smith from the neighbourhood of Berbera, and presented by His Highness the Gaekwar of Baroda; the other presented by Major R. G. Edwards Leckie (of the Canadian Mounted Rifles), and collected by him during an exploration-tour, from Upper Sheikh and Garrasgooi in the Golis-Range district, and also from the Eilo Range of mountains.

In the course of my official duties at the British Museum, I have been entrusted with the examination of these new collections, with the view of describing the individual specimens, as well as of ascertaining their importance with regard to the stratigraphy of the country.

In carrying out this work, a large amount of comparison with species already known from Somaliland and elsewhere has been imperative, while the limestone-matrices surrounding the different specimens have been microscopically examined in several cases, in order that the best confirmatory evidence should be obtained as to geological horizons. This examination has rendered necessary a revision of some of the geological and palæontological conclusions referred to in Prof. Gregory's memoir, for which I am largely responsible in connection with the determination of certain molluscan remains therein mentioned. The new material before us is, generally speaking, better preserved than that dealt with previously, and especially does this remark apply to the mollusca. There are good

*Topographical map of British Somaliland, by Major R. G. Edwards Leckie.*



fragmentary casts of large turriculate shells belonging to the genus *Campanile* of the family Cerithiidae, which, on account of certain plications on the columella, were erroneously considered as *Nerinea* and consequently of Cretaceous age; there are also large casts of Luciniform shells, as well as other lamellibranchs and gastropods to which special reference need not now be made. It is sufficient, for the present, to state that the forms of mollusca here indicated are characteristic of Eocene rocks generally, and that with regard to the specimens from Somaliland further evidence is afforded of their Eocene age by the presence of certain foraminifera which enter into the minute structure of the limestone-matrices.

The new collections embrace no older fossils than may safely be ascribed to an Eocene age, excepting some remains of ammonites and belemnites found by Major Leckie in the Eilo Range of Western Somaliland, which belong to Mesozoic rocks, and are therefore not considered in this paper.

The corals described by Prof. Gregory came from the 'Urada' and 'Dobar' Limestones, these formations being regarded as Turonian and Neocomian respectively, although he thought that the upper part of the Urada Limestone might be of Eocene age, on account of the discovery in its structure by Messrs. Sherborn & Chapman of *Nummulites*, *Amphistegina*, and *Orbitoides dispansa*, all of which were found associated with a large *Conoclypeus* (?) sp. described in the same memoir. No nummulites have been detected in the present material, but *Operculina complanata*<sup>1</sup> has been determined, together with *Amphistegina* and *Orbitoides dispansa*. This particular form of Orbitoid, exhibiting rectangular chambers in the median plane, is acknowledged by most authorities on the Foraminifera to be indicative of an Eocene age.

It is evident, from an examination of the specimens in these different collections, that there are two limestones represented—an upper one, which is a massive cherty rock, frequently reddish-brown externally; and a lower, of less cherty character, and generally of a lighter colour, although sometimes red-stained. According to Major Leckie, these two sets of limestones are conformable to each other, and therefore without any great difference in age to account for. Further, they may be regarded as the equivalents of the so-called 'Urada' and 'Dobar' Limestones, previously diagnosed as Cretaceous but which now appear to belong to Tertiary times.

These Somaliland limestones are probably capable of correlation with those of South-Eastern Arabia, as well as with those of Scind and Cutch in India; for, according to the researches of H. J. Carter, *Orbitoides dispansa*, *Operculina*, etc., occur in all three regions of Asia. Carter<sup>2</sup> also referred to the occurrence of molluscan casts in the

<sup>1</sup> As understood by W. B. Carpenter, W. K. Parker, & T. R. Jones, 'Introduction to the Study of the Foraminifera' Ray Soc. (1862) pp. 247-62 & pl. xvii.

<sup>2</sup> 'Memoir on the Geology of the South-East Coast of Arabia' [reprinted, with alterations and additions, from the Journ. Bombay Branch R. Asiat. Soc. 1852, vol. iv], Geological Papers on Western India, etc. (1857) pp. 551-627.

Arabian deposits, especially large Naticoid shells, a small *Gryphæa*, and Spatangoid echinoderms. A collection of Tertiary fossils from Ras Ghissa (Arabia) was made a few years ago by Lieut.-Col. Dr. A. S. G. Jayakar, and presented to the British Museum, containing yellowish limestone-casts of Naticoid shells and a *Campanile* resembling those from Somaliland, while the matrix of these specimens exhibited foraminiferal organisms, particularly an abundance of *Operculina* and *Amphistegina*.

But, as well as this correlation of the Somaliland Tertiary limestones with those of Arabia and India, somewhat similar palæontological resemblances may be traced in the Eocene rocks of Egypt and other countries of Northern Africa (Nigeria,<sup>1</sup> the Cameroons,<sup>2</sup> etc.), through Southern Europe to the Paris Basin, and so on to the Bracklesham Beds of England.

## II. LITERATURE.

A brief review of the various papers on the entire palæontology of Somaliland will now be given in chronological order.

The earliest record of fossils from Somaliland was made by H. J. Carter<sup>3</sup> in 1857, who determined the following specimens, but without descriptions or illustrations, obtained by Capt. (afterwards Sir Richard) Burton from the neighbourhood of Berbera, and correlated them with the Jurassic fauna of Cutch in India:—

*Belemnites canaliculatus*, Schlotheim.

*Terebratula intermedia*, J. Sowerby.

*Terebratula microrhyncha*, J. de C. Sowerby.

*Arca* (sp.?).

*Exogyra auricularia*, Goldfuss.

A number of specimens from Ouarsangueli (= Warsangeli) were described and partly figured by Dr. A. T. de Rochebrune<sup>4</sup> as of Neocomian age, the horizontal fossil being *Ostrea Couloni*, DeFrance. New names were given to the other species, the whole series comprising three gastropods, seventeen lamellibranchs, one echinoid, and one coral.

Miss C. A. Raisin,<sup>5</sup> in a petrographical paper, referred to some limestones containing foraminifera (*Amphistegina*, *Globigerina*, etc.), polyzoa, etc., which she considered might be late Cretaceous or

<sup>1</sup> A. de Lapparent [Northern Nigerian Eocene], *Comptes Rendus Acad. Sci. Paris*, vol. cxxxvi (1903) p. 1118; R. B. Newton, *Geogr. Journ.* vol. xxiv (1904) pp. 522-24, & *Ann. & Mag. Nat. Hist.* ser. 7, vol. xv (1905) pp. 83-91 & pl. v; and F. A. Bather, *Geol. Mag.* 1904, pp. 292-304 & pl. xi.

<sup>2</sup> P. Oppenheim [Eocene Fossils from the Cameroons], *Centralblatt für Min. Geol. Pal.* (Stuttgart) 1903, pp. 373-74; and 'Beiträge zur Geologie von Kamerun' 1904, pt. iii, pp. 243-85, pls. vi-ix.

<sup>3</sup> [Jurassic Fossils from near Berbera], 'Memoir on the Geology of the South-East Coast of Arabia' in *Geological Papers on Western India*, etc. (1857) p. 622.

<sup>4</sup> 'Observations Géologiques & Paléontologiques sur la Région habitée par les Comalis & plus spécialement sur les Montagnes des Ouarsanguélis'; in Georges Révoil's 'Faune & Flore des Pays Comalis' 1882, pp. 39 & pls. i-iv.

<sup>5</sup> 'Rock-Specimens from Somaliland' *Geol. Mag.* 1888, pp. 417-18.

Tertiary—possibly Miocene age. This material was obtained by Capt. King at Mount Eilo, south of Zeila (lat.  $10^{\circ} 30' N.$ , and long.  $43^{\circ} 35' E.$ ).

A series of Neocomian fossils were described and figured by Prof. C. Mayer-Eymar<sup>1</sup> during 1893, which had been collected by Prof. Keller on the south-western slopes of the Somali plateau, along the valley of the Faf, a tributary of the Webi Shebeli. It consisted of cephalopods, gastropods, lamellibranchs, and echinoids, which in the aggregate were referred to four already-known species and eleven new forms.

During the year 1896, Prof. J. W. Gregory<sup>2</sup> published a list of Jurassic fossils from Bihin collected by Mrs. Lort-Phillips, which were determined by Messrs. G. C. Crick,<sup>3</sup> R. Bullen Newton,<sup>4</sup> and F. A. Bather as *Belemnites subhastatus*, Zieten, *Parallelodon Egertonianus*, Stoliczka, *Rhynchonella Edwardsi*, Chapuis & Dewalque, and *Rh. subtetrahedra*, Davidson. In the same paper Prof. Gregory described a new species of coral, under the name of *Cryptocænia Lort-Phillipsii*, found in the Duba Limestone, which he doubtfully referred to the Neocomian age.

Prof. Gregory<sup>5</sup> noted the value of a single specimen of *Rhynchonella subtetrahedra*, determined by Dr. F. A. Bather, which was found by Dr. Donaldson Smith in Somaliland, as indicating the presence of Jurassic rocks in that region.

Four forms of *Perisphinctes* collected by Dr. Donaldson Smith from the rocks of Tug Turfa, were described by Mr. G. C. Crick<sup>6</sup> and regarded as characteristic of an Upper Jurassic horizon.

Prof. Gregory's<sup>7</sup> most comprehensive paper on the Somaliland fossils was published in 1900. It contained descriptions of the corals and echinoids found in the raised-reef and plateau-limestones of that country, together with certain molluscan determinations made by the present writer, as well as forms of foraminifera identified by Messrs. C. D. Sherborn & F. Chapman, and some brachiopods determined by Dr. F. A. Bather. The horizons recognized were post-Pliocene, Eocene (?), Turonian (or Cenomanian?), Neocomian, and Jurassic.

<sup>1</sup> 'Neocomian-Versteinerungen aus dem Somaliland' Vierteljahrsschr. naturf. Gesellsch. Zürich, vol. xxxviii (1893) pp. 249-65 & pls. i-ii.

<sup>2</sup> 'A Note on the Geology of Somaliland, based on Collections made by Mrs. E. Lort-Phillips, Miss Edith Cole, & Mr. G. P. V. Aylmer' Geol. Mag. 1896, pp. 289-94.

<sup>3</sup> 'Note on some Fragments of *Belemnites* from Somaliland' Geol. Mag. 1896, pp. 296-98.

<sup>4</sup> 'On the Occurrence of an Indian Jurassic Shell, *Parallelodon Egertonianus*, in Somaliland, Eastern Africa' Geol. Mag. 1896, pp. 294-96.

<sup>5</sup> 'Note on Dr. A. Donaldson Smith's Geological Collection' [from Somaliland]; Appendix E to Donaldson Smith's 'Through Unknown African Countries' 1897, pp. 423-25.

<sup>6</sup> 'On the Fossil Cephalopoda from Somaliland collected by Dr. Donaldson Smith'; Appendix F, *op. cit.* pp. 426-29.

<sup>7</sup> 'On the Geology & Fossil Corals & Echinids of Somaliland' Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 26-45 & pls. i-ii (with sketch-map & sects. in the text).

A new form of *Heliopora* collected by Mrs. Lort-Phillips from the Uradu Limestone near the Rugga Pass, was described and figured by Prof. Gregory<sup>1</sup> as *Heliopora somaliensis*, and regarded as of Turonian age.

In 1901, Herr Oscar Neumann<sup>2</sup> announced the discovery of Jurassic and early Cretaceous fossils at various localities in Gallaland, material which is under description by Dr. Edgar Dacqué,<sup>3</sup> a first fasciculus having been issued in 1904 on the 'Untere Kreide,' containing figures and descriptions of mollusca—*Exogyra Couloni*, Defrance, *Cucullaea Gabrielis*, Leymerie, *Pholadomya Picteti*, Mayer-Eymar, etc., from the Neocomian; and *Trigonia Picteti*, Coquand, etc., from the so-called Aptian(?). *Astrocenia subornata*, d'Orb. var. *africana*, Weissermel, is also described by Dr. Dacqué from Neocomian strata of this part of Africa.

### III. DESCRIPTION OF THE FOSSILS.

#### (a) Gastropoda.

#### Remarks on the Genus *Campanile* as found in Somaliland.

Among the specimens mentioned in Prof. Gregory's memoir of 1900, were some more or less silicified limestone-casts of large gastropodan shells which, on account of possessing the plaited columella, were identified by the present writer as *Nerinea*, and consequently classed as Cretaceous in age. They were referred to as fossils of the '*Nerinea*-Limestone' from Dongorreh and Bur-Dab, and regarded as Neocomian, under the following identifications—*Nerinea*, sp. nov., and *Nerinea* allied to *Renauxiana*, d'Orb.

The further material from Somaliland that has now been studied embraces some better specimens than were formerly available, so that these shells can be recognized as belonging to the family of the Cerithiidae and to the genus *Campanile*,<sup>4</sup> the type of which is *Cerithium giganteum* of Lamarck, a species characterizing the Lutetian or Middle Eocene rocks of England, the Continent of Europe, Northern Africa, Asia Minor, etc. It is to this type that the different forms from Somaliland are undoubtedly related. There is always considerable difficulty in dealing with casts at any time, but careful comparison of them on the present occasion with many

<sup>1</sup> '*Polytremacis* & the Ancestry of Helioporidae' Proc. Roy. Soc. vol. lxvi (1900) p. 298 & pl. ii, figs. 8 a-c.

<sup>2</sup> 'Ueber jurassische & die ersten cretaceischen Versteinerungen aus den Galla-Ländern' Zeitschr. Deutsch. Geol. Gesellsch. vol. liii (1901) Verhandl. pp. 100-102.

<sup>3</sup> 'Beiträge zur Geologie des Somalilandes: I. Untere Kreide' Beitr. zur Paläont. & Geol. Oesterreich-Ungarns & des Orients, vol. xvii (1904) pp. 7-20 & pls. ii-iii.

<sup>4</sup> *Campanile* of Bayle, in Paul Fischer's 'Manuel de Conchyliologie' fasc. vii (1884) p. 680.

specimens from other localities, has enabled me to prepare the following notes on the examples from Somaliland now preserved in the British Museum.

Before entering upon these descriptions, it may be interesting to point out that casts of *Campanile* have been previously mistaken for *Nerinea*. A notable case was that of Bellardi's *Nerinea Serapidis*,<sup>1</sup> founded on the cast of a fragmentary whorl from the Nummulitic formation of Egypt, showing internal characters, with the markings of three prominent plications which were originally produced by the columella. Similar fragments from Egypt are in the British Museum, as well as more perfect specimens, all of which exhibit this strongly-plicated columella extending through the entire axis of the shell, which, as a cast either in limestone or as an impression taken in ordinary modelling-wax, will produce a result exactly similar to that figured by Bellardi. That is, it would appear that, in all these natural casts, the original solid columella has been dissolved away during the process of fossilization, but not before leaving its plicated character fully impressed on the internal walls of the volutions. Moreover, in all true specimens of *Nerinea*, the outer lip is plicated as well as the columella; but, in members of the Cerithiidae, such a character is wanting. With regard to another form of *Nerinea* described as *N. supracretacea*, Bellardi, from the Nummulitic rocks of Nice, it is possible, as suggested by Stoliczka,<sup>2</sup> that the absence of plications on the outer lip of that specimen may be due to its worn condition; and that, instead of coming from the Nummulitic rocks, it probably came from the Cretaceous deposits which also occur in the neighbourhood of Nice. So far, therefore, as can be ascertained, no authentic *Nerinea* is known in the Tertiary Period, and it appears to be a genus absolutely restricted to Secondary rocks.

All these large forms of *Campanile* appear to be characteristic of Middle Eocene times. F. Bayan has described and figured *C. Bedechei*, with a basal diameter of 61 millimetres, from the Paris Basin, as well as *C. Lachesis*, measuring from 65 to 90 mm., from the 'Nerita Schmiedeli-beds' of Ronca.<sup>3</sup> From Asia Minor, A. d'Archiac figured and described *C. Tchihatcheffi*, which has a basal measurement of 90 mm., and is found associated with *Nummulites Ramondi* and *N. scabra*; also *C. Leymeriei*, with a basal width of 140 mm., from the same horizon.<sup>4</sup>

#### CAMPANILE cf. GIGANTEUS (Lamarck) Var. A. (Pl. XVII, fig. 1.)

*Cerithium giganteum*, Lamarck, Ann. Mus. Hist. Nat. Paris, vol. iii (1803) p. 439; J. Sowerby, 'Mineral Conchology' vol. ii (1818) p. 199 & pl. clxxxviii, fig. 2;

<sup>1</sup> 'Mem. R. Accad. Sci. Torino, ser. 2, vol. xv (1855) p. 178 & pl. i, fig. 9.

<sup>2</sup> 'Palæont. Indica: Cretaceous Fauna of Southern India,' Mem. Geol. Surv. India, vol. ii (1867-68) p. 179.

<sup>3</sup> 'Études faites dans la Collection de l'Ecole des Mines: Fossiles nouveaux ou mal connus' Fasc. i, Moll. Tertiaires, 1870, pp. 31-33.

<sup>4</sup> In Tchihatcheff's 'Asie Mineure' Paléontologie (1866-69) pp. 126-29 & pl. i, figs. 1-2, pl. ix, figs. 2-3, & pl. ii, fig. 1.

Deshayes, 'Description des Coquilles Fossiles des Environs de Paris' vol. ii (1833) p. 300 & pl. xlii, figs. 1-2.

*Campanile giganteum*, Bayle, in Fischer's 'Manuel de Conchyliologie' fasc. vii (1884) p. 680.

This specimen consists of a large limestone-cast exhibiting the basal and penultimate whorls only, the remainder of the spire being absent. The whorls are shallow, infundibuliform, postero-horizontally depressed, obtusely angulate at and between the margins, and separated by a deep suture; the margin of the inner or columella-lip is smooth, rounded, thickened, and excavated; the aperture is filled with matrix and not definable, but, where this is rubbed down, columella-plications are observed to be present. The surface of the whorls shows indications of one or two obscure spiral bands, which give rise to obtuse angulations apart from that produced by the marginal carination.

#### DIMENSIONS IN MILLIMETRES.

Basal whorl {	Diameter.....=100	Penultimate whorl {	Diameter ...=85
	Height.....= 70		Height .....=30

Although not quite so rounded in its whorls, this specimen is closely related to a large internal cast in the British Museum (Mantell Coll. 32578) labelled *Campanile* cf. *giganteus*, from the Eocene (Lutetian) strata of Verona, Italy, which exhibits three prominent columella-plications extending through its whole axis. The specimen now described was previously regarded as 'a *Nerinea* of Neocomian affinities';<sup>1</sup> but a further study of its characters removes all doubt as to its proper place being with the large Cerithiidae, so characteristic of the Eocene Period. That it belongs to this horizon is a fact further strengthened by the presence of *Amphistegina* and *Operculina* cf. *complanata* in the limestone-matrix (see § P in the Notes on the Foraminiferal Structures, etc., p. 177).

Locality.—Bur Dab (Somaliland).

Collector.—Mr. F. B. Parkinson. [G. 12053.]

Matrix.—Cream-coloured limestone, weathering a straw-colour.

#### CAMPANILE cf. GIGANTEUS (Lam.) Var. B. (Pl. XVII, figs. 2 & 3.)

This form is represented by a basal fragment possessing four whorls, which have been more or less distorted or compressed through the process of fossilization. The whorls are obtusely angulate on both margins, infundibuliform, deeply sutured, depressed and concave above; they are of uniform height, with the exception of the last, which is about double that of the others. The base shows two strong columella-plications, and there may be a third, but it is not exposed. The surface of the last whorl possesses distant concentric sulcations, about midway between the lower marginal angulation and the basal area.

<sup>1</sup> See R. B. Newton in Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 43.



## DIMENSIONS IN MILLIMETRES.

Height of the specimen .....=70	Height of the last whorl ...=30
Basal diameter (maximum)...=65	

The example here described was collected at Dongorreh by Mrs. Lort-Phillips, its matrix containing *Amphistegina*, *Operculina*, etc. (see § O in the Notes on the Foraminiferal Structures, p. 177). There is a second specimen of this variety, which was obtained by Mr. F. B. Parkinson at the same place, and was erroneously recognized as *Nerinea* allied to *Renauviana*, d'Orb.<sup>1</sup> A further specimen was collected by Major R. G. Edwards Leckie about 4 miles south of Camp, Upper Sheikh, at an altitude of over 5000 feet, showing similar lithological characters to the others. It is, however, of smaller size, having a basal diameter of 55 millimetres, although the whorls are of precisely the same type of structure as that described.

Localities.—Dongorreh; 4 miles south of Camp, Upper Sheikh.

Collectors.—Mrs. Lort-Phillips, Mr. F. B. Parkinson, and Major R. G. Edwards Leckie.

Matrix.—Heavy cherty limestone, red-stained externally.

## CAMPANILE SOMALIENSIS, sp. nov. (Pl. XVIII, figs. 1 &amp; 2.)

There are two limestone-casts now to be noticed, of still larger proportions than those previously described, which apparently belong to one and the same species. The best-preserved and largest of these exhibits a conically-shaped body of oblong circumference with the four last whorls, all the earlier ones being absent. The latest whorl shows a maximum height of 72 millimetres, while the penultimate measures 40 mm. in the same direction, the next giving a height of 35 mm. The basal diameter of the specimen measures 165 by 145 mm. Its base is much covered with matrix, but concentric plications are observable round the columellar region, where a flattened area is noticed circumscribing the axis. The whorls of this specimen are not funnel-shaped anteriorly, nor is the suture so deep as in the forms previously described. Moreover, it is doubtless of much shorter spire also, and is probably a form not yet described. Indications of a short anterior canal are also present.

The smaller of these specimens (having a diameter of 135 by 120 millimetres) has been cut through longitudinally, for the exposition of internal characters. This exhibits a wide cylindrical axis showing columella-plications, having on each side large quadrate chambers with rounded outer margins, and curving obliquely and anteriorly inwards.

Locality.—Specimens collected by Dr. Donaldson Smith in the neighbourhood of Berbera, and presented to the British Museum (Natural History) by the Gaekwar of Baroda.

Matrix.—A cream-coloured cherty limestone, containing *Orbitoides*, *Operculina*, etc. (see § L in the Notes on the Foraminiferal Structures, p. 176).

<sup>1</sup> See R. B. Newton in Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 43, footnote.

*EUSPIRA* cf. *SCALARIFORMIS* (Deshayes). (Pl. XIX, figs. 1 & 2.)

*Ampullaria scalariformis*, Deshayes, 'Description des Coquilles Fossiles des Environs de Paris' vol. ii (1825) p. 138 & pl. xvi, figs. 8-9.

*Euspira scalariformis*, Cossmann, 'Catal. illustré Coq. Foss. Éocènes des Environs de Paris' Ann. Soc. Roy. Malacol. Belg. vol. xxiii (1888) p. 175.

This form of gastropod is represented by a fragmentary limestone-cast, exhibiting the penultimate and last whorls of a large shell of ovately-conical shape. The last whorl is convex, long, and surmounted by a somewhat flattened area, bordered by an angulated margin. The umbilical region is excavated, although partly filled with matrix; and the aperture is of distinctly-oval contour, vertically elongate, narrow, with nearly-parallel sides, and showing a measurement of 63 by 35 millimetres.

The specimen has all the appearance of a close relationship to *Euspira scalariformis*, having been probably furnished with just as prominent a spire as that which characterizes that species when in a more perfect condition. The species was originally recorded from the Middle Eocene of France.

Locality.—Near Berbera.

Collector.—Dr. Donaldson Smith. Presented to the British Museum (Natural History) by the Gaekwar of Baroda.

Matrix.—Greyish cherty limestone.

*EUSPIRA* cf. *HYBRIDA* (Lamarck). (Pl. XIX, figs. 3 & 4.)

*Ampullaria hybrida*, Lamarck, Ann. Mus. Hist. Nat. Paris, vol. v (1804) p. 33.

*Natica hybrida*, Deshayes, 'Description des Coquilles Fossiles des Environs de Paris' vol. ii (1829) p. 172 & pl. xix, figs. 17-18.

*Euspira hybrida*, Cossmann, 'Catalogue illustré des Coquilles Fossiles Éocènes des Environs de Paris' Ann. Soc. Roy. Malacol. Belg. vol. xxiii (1888) p. 175.

*Natica* allied to *Hugardiana*, R. B. Newton, in Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 43 (footnote), *non* d'Orb.

This specimen was originally recognized as Cretaceous, under the name of *Natica* allied to *Hugardiana*, but it is apparently a form not far removed from *Euspira hybrida*, so characteristic of most Eocene localities. It shows a graduated and conical spire with the prominent 'rampe' or platform constituting the summit-area of each whorl. The last whorl is inflated, and excavated at the base, where there are indications of a large rounded callosity. The aperture is semi-oval. Parts of four whorls are traceable in this cast, the more delicate earlier ones not, of course, being present.

## DIMENSIONS IN MILLIMETRES.

Height of the specimen ...=65	Height of the last whorl .....=37
Diameter (dorsal view) ...=63	

There is also a smaller cast, which may be referred to this species.

Localities.—Bur Dab (Parkinson); and Garrasgooi, 3 miles south-west of Upper Sheikh (Leckie).

Collectors.—Mr. F. B. Parkinson and Major R. G. E. Leckie.

Matrix.—Cream-coloured limestone.

Another Naticoid shell, of far larger dimensions than that just described, but probably related to *Euspira hybrida*, is among the specimens obtained by Dr. Donaldson Smith. It consists of a limestone-cast with four whorls, the last being of considerable size and showing a well-defined 'ramped' area. The basal region appears to have been removed by longitudinal splitting or weathering, so that a flat surface only is seen, representing a section with a large central umbilical space. The spiral diameter of this specimen measures 125 by 95 millimetres.

In a microscope-slide of the matrix, *Operculina*, *Amphistegina*, etc. are seen to enter largely into its minute structure (see § M in the Notes on the Foraminiferal Structures, p. 176).

Locality.—Near Berbera.

Collector.—Dr. Donaldson Smith. Presented to the British Museum (Natural History) by the Gaekwar of Baroda.

Matrix.—Cream-coloured limestone.

#### SOLARIUM cf. CANALICULATUM, Lamarck. (Pl. XIX, figs. 5 & 6.)

*Solarium canaliculatum*, Lamarck, Ann. Mus. Hist. Nat. Paris, vol. iv (1804) p. 53; Deshayes, 'Description des Coquilles Fossiles des Environs de Paris' vol. ii (1832) p. 220 & pl. xxiv, figs. 19-21; J. de C. Sowerby, 'Mineral Conchology' vol. vi (1826) p. 43 & pl. dxxiv, fig. 1.

Represented by two weathered limestone-specimens, in the collection formed by Major Leckie, which mostly agree in shape, sculpture, and size with this well-known European Eocene shell. The granulose spiral lines of the upper surface, as well as those of the basal region, are well defined, although probably more regular than in the type.

#### DIMENSIONS IN MILLIMETRES.

Height (probable) ..... = 8 | Diameter of the base ..... = 10

One of the specimens is associated in the same matrix with *Liotina somaliensis* and a coral, probably *Calamophyllia Aylmeri* of Gregory; while the other example occurs with an Astartiform shell of doubtful determination.

Locality.—Top of Garrasgoi Mountain, 5200 feet above sea-level, south-west of Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Heavy, compact, cherty limestone, of reddish colour externally.

#### LIOTINA SOMALIENSIS, sp. nov. (Pl. XIX, fig. 7.)

Shell small, turbate, summit depressed; whorls convex, deeply sutured, and ornamented with an elevated trellised sculpture, composed of numerous longitudinal and spiral costæ, forming regular quadrangular spaces. Margin of aperture thickened, varixed, and reflected. Basal characters not seen.

#### DIMENSIONS IN MILLIMETRES.

Height ..... = 12 | Diameter ..... = 12

Represented by a beautifully-weathered example on the limestone-matrix, associated with *Solarium* cf. *canaliculatum* and a coral, probably *Calamophyllia Aylmeri*, Gregory.

This form differs from *Liotina* (*Delphinula*) *fimbriata*, Deshayes, from the Paris-Basin Eocene, which it somewhat resembles in sculpture, by its much smaller trellised ornamentation, caused by the greater number of spiral and longitudinal costæ. A minute tuberculation is also apparent in the ornamentation, which is caused by a thickening at the junctions of the two sets of costæ. The spire consists of five or six whorls, the last of which has a height at the aperture of 8 millimetres, or nearly three times that of the succeeding one.

Locality.—Top of Garrasgooi Mountain, 5200 feet above sea-level, south-west of Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Heavy cherty limestone, reddish-brown externally.

### Indeterminable Gastropoda.

Among Major Leckie's fossils from the limestones of Garrasgooi are some further forms of gastropods which, although possessing a certain Eocene facies, are unfortunately not capable of identification. These include natural casts of a *Trophon* (?); *Turritella*, showing two elongate whorls of a large species; and a *Conus* resembling somewhat *C. deperditus* of Bruguière, or *C. diversiformis* of Deshayes, from the English and Continental Eocene deposits, or the Indian (Cutch) species *C. militaris*, figured and described by J. de C. Sowerby,<sup>1</sup> from beds of similar age.

Locality.—Garrasgooi, 3 miles south-west of Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—A light-coloured limestone, and found below the more cherty rock containing *Liotina somaliensis* and other fossils.

### (b) Lamellibranchia.

#### ALECTRYONIA cf. MARTINSI (d'Archiac). (Pl. XX, figs. 1 & 2.)

*Ostrea orbicularis*, J. de C. Sowerby, Trans. Geol. Soc. ser. 2, vol. v (1840) pl. xxiv, fig. 8; non Linnæus.

*Ostrea Martinsii*, A. d'Archiac, 'Descr. Foss. Groupe Nummul.' Mém. Soc. Géol. France, ser. 2, vol. iii, pt. ii (1850) p. 438 & pl. xiii, fig. 25.

*Ostrea Alectryonia Martinsii*, Frauscher, Denkschr. d. k. Akad. Wissensch. Wien, vol. li (1886) pt. ii, p. 68 & pl. iii, figs. 4-6.

*Alectryonia rectangularis*, R. B. Newton in Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 43; non Römer.

*Ostrea (Alectryonia) semipectinata*, Schafhäutl in Oppenheim, Palæontographica, vol. xxx, pt. iii (1903) p. 43.

This specimen was previously regarded by me as a Cretaceous shell, under the name of *A. rectangularis* of Römer, but re-examination shows that its true place is in close association with *Alectryonia Martinsii*, originally described by J. de C. Sowerby from the Nummulitic formation of India under the pre-occupied name

<sup>1</sup> Trans. Geol. Soc. ser. 2, vol. v (1840) pl. xxvi, fig. 34.

of *Ostrea orbicularis*. It represents a fragment of a slightly-convex valve, showing a shallow ligamental area with a straight horizontal inner margin. The ribs are prominent and bifurcating, the channels between them being deeply excavated, and so producing a plicated margin. The surface is much worn, consequently there are no traces of an imbricated structure. It resembles very closely J. de C. Sowerby's original figure, as well as Dr. Frauscher's illustrations of examples from districts of the Northern Alps. Dr. Oppenheim regards this species as equivalent to Schafhäutl's *Ostrea semipectinata*, *suborbiculata*, and *abscissa*, and unites all three under the first-named species; but Schafhäutl's figures are so obscure for such a determination, that it is far better to retain *Martinsi* of A. d'Archiac. It is, however, interesting to know from Dr. Oppenheim's memoir that this shell is recognized in the Egyptian Eocene; and the present Somaliland example appears to offer characters of such close relationship as to make it almost certain that it is a second instance of its occurrence in Northern Africa.

Locality.—Dobar, south of Berbera.

Collector.—Mrs. Lort-Phillips.

Matrix.—The so-called 'Dobar Limestone.' [B.M.—L. 14927.]

*GRYPHÆA GREGORYI*, sp. nov. (Pl. XVII, fig. 4 & Pl. XXI, figs. 1 & 2.)

*Gryphæa vesiculosa*, R. B. Newton in Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 43; non J. de C. Sowerby.

Shell small, thin, strongly arched, sides abrupt, subrhomboidal, summit depressed; growth-lamellæ irregular and sinuated at the lateral lobe; umbonal area incurved; anterior margin extended at the hinge, and forming a small auricle; posterior lobe well-defined, expansive and moderately concave externally.

#### DIMENSIONS IN MILLIMETRES.

Umbono-ventral .....	=27	Convexity of the left valve ...=25
Antero-posterior .....	=25	

This species is founded on external characters of the lower or left valve only, of which there are several examples more or less fragmentary, both in Major Leckie's collection and in that formed by Mr. Parkinson, referred to in Dr. Gregory's paper as a Cenomanian fossil with the name of *Gryphæa vesiculosa*. The specimen described and figured belongs to this latter collection, being preserved in the British Museum under the registered number L. 12666.

The present species is related to several Eocene forms of this genus, such as *Gr. eversa*, Melleville, from France, *Gr. laticeps*, Schafhäutl, from Kressenberg, and *Gr. Escheri* of Mayer-Eymar, which includes *Gr. gryphovicina*, S. V. Wood, and *Gr. pseudovesicularis*, Gümbel, from England, the Northern Alps, and Kressenberg; but it is well separated by its subrhomboidal form, its strongly-arched central region, the somewhat steep sides, and rather wide but not produced lobe of the posterior area. For synonymy and further particulars of these species reference should be made to an important

memoir by Dr. K. F. Frauscher, 'Das Unter-Eocän der Nordalpen & seine Fauna' Denkschr. d. k. Akad. d. Wissensch. Wien, vol. li (1886) pt. ii, pp. 49-55.

The specific name is given in honour of Prof. J. W. Gregory, my former colleague in the Geological Department of the British Museum (Natural History), who at the time of the reading of this paper was Professor of Geology in the University of Melbourne, but now occupies a similar position in the University of Glasgow.

Localities.—Northern Somaliland [B.M.—L. 12666]; and top of Garrasgooi Mountain, at an elevation of about 5200 feet, 3 miles south-west of Sheikh.

Collectors.—Mr. F. B. Parkinson and Major R. G. Edwards Leckie.

Matrix.—Cherty limestone, coloured reddish-brown externally.

*GRYPHÆA* sp. (Pl. XXI, fig. 3.)

Major Leckie has collected three fragments of a large *Gryphæa* which, from want of better evidence, it is difficult to associate with any known form of this genus, although possibly they may be related to an Indian Nummulitic species described by J. de C. Sowerby as *Gryphæa globosa*.<sup>1</sup> The largest of the pieces represents the central portion of a lower valve, which gives an umbono-ventral measurement of 75 millimetres. It is considerably arched and incurved at the umbonal region, and the external surface, although in a worn condition, still shows some wide lamellæ of growth with occasional obscure concentric banding between them. This specimen also exhibits a shell-wall of great thickness (13 millimetres) at the umbonal arch, which gradually decreases, however, towards the ventral margin, where it is only about 6 mm. thick. No ligamental or other internal characters are definable.

Locality.—About 3½ miles south of Camp at Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Cherty limestone, coloured reddish-brown externally, and containing *Discocyclina dispansa*, *Operculina*, and *Amphistegina* (see §§ B & C in the Notes on the Foraminiferal Structures, p. 176).

*VULSELLA* (?) sp. (Pl. XXI, fig. 4.)

This specimen consists of a narrow elongate valve, showing a convex and a somewhat acuminate umbonal region, the remainder of the surface being depressed. The lateral margins are imperfect, and consequently the original antero-posterior measurements are unknown. The principal feature of the specimen is its sculpture, exhibiting a regular series of concentric lamellæ, which are very thin, nearly equidistant, and smooth. In this ornamentation there is a certain agreement with some forms of *Vulsella*, recently described and figured by Dr. P. Oppenheim, from the older Tertiary strata of Egypt.<sup>2</sup> But it is hazardous to say more in regard to the

<sup>1</sup> Trans. Geol. Soc. ser. 2, vol. v (1840) pl. xxv, fig. 16.

<sup>2</sup> Palæontographica, vol. xxx, pt. iii (1903) pl. vi.

present imperfect material, especially as the specimen here figured is without hinge or internal characters. It might even represent the upper valve of a *Gryphæa*, similar to the larger form referred to in this paper.

DIMENSIONS IN MILLIMETRES.

Umbono-ventral ..... = 58 | Antero-posterior (about) ..... = 37

Locality.—Garrasgooi Mountain, about 5200 feet above sea-level, south-west of Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Cherty limestone, coloured reddish-brown externally.

*SPONDYLUS ÆGYPTIACUS*, R. B. Newton.

*Spondylus ægyptiacus*, R. B. Newton, Geol. Mag. 1898, p. 536 & pl. xx, figs. 4-6; Cossmann, Bull. Inst. Egyptien, ser. 4, no. 1, fasc. vi (1901) p. 190 & pl. ii, fig. 21; P. Oppenheim, Palæontographica, vol. xxx, pt. iii (1903) p. 63 & pl. iii, figs. 1-2.

The examples referred to this species are very fragmentary, although showing typical sculpture-details, including the two orders of radial costæ, presenting a more or less zoned appearance caused by the occasional presence of finer costæ between the interstitial spaces. The costæ also exhibit minute spinous projections, an additional character pointed out by M. Cossmann since the publication of the original description.

This species was first described from the Eocene of Egypt, and it has since been identified from the same country by M. Cossmann and Dr. Paul Oppenheim, in rocks of similar age.

Localities.—Hill about 4 miles south of Upper Sheikh at a height of 5000 feet; top of Garrasgooi Mountain, about 5200 feet, south-west of Upper Sheikh; Bur Dab.<sup>1</sup>

Collectors.—Major R. G. Edwards Leckie and Mr. F. B. Parkinson.

Matrix.—Cherty limestone, of reddish colour externally.

*SPONDYLUS SOMALIENSIS*, sp. nov. (Pl. XXI, figs. 5, 6, & 6 a.)

Species of variable size, sub-ovate, regularly convex, and nearly equivalve; external surfaces ornamented with numerous (probably about 60) well-defined, rounded, longitudinal costæ, all of one order, which are covered with frequent infundibuliform annulations having thin and elevated margins: these occasionally protrude beyond the others to form spinous projections, more especially on the lateral regions. The costæ are separated by extremely narrow and rather deep grooves; the hinge-line is short, with its umbono-lateral areas obliquely ribbed. No internal characters are seen.

DIMENSIONS IN MILLIMETRES.

(Imperfect specimen with contiguous valves.)	Antero-posterior (about) ..... = 28
Umbono-ventral ..... = 42	Maximum depth ..... = 28

<sup>1</sup> Fragments referred to a Cenomanian age under the name of *Spondylus* sp., by R. B. Newton, in Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 43.

This species is represented by fragmentary specimens showing a variation in size, the most perfect of which possesses both valves and is of medium measurement (see dimensions as above); two fragments of considerably larger specimens exhibit the sculpture-characters in a good state of preservation. It differs from *Spondylus ægyptiacus* in its surface-ornamentation, having ribs of only one order, that is, without secondary or intermediate ribs; in the closely-imbricated character of its costæ; and in its nearly-equivalve condition. The fragment from Bur Dab, referred to by me, in Prof. Gregory's paper, as belonging probably to a new species of *Pecten*, is, on comparison with the later improved material, found to be a fragment of the *Spondylus* now described.

Localities.—Top of Garrasgoi Mountain, at an elevation of about 5200 feet; and Bur Dab.

Collectors.—Major R. G. Edwards Leckie and Mr. F. B. Parkinson.

Matrix.—Cherty limestone, red-stained externally.

#### LITHOPHAGA sp. (Pl. XXI, fig. 7.)

*Modiola Ferreti*, R. B. Newton in Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 43; non A. T. de Rochebrune.

These examples of a *Lithophaga* are represented by crypts, contained in a compound coral which Prof. Gregory has named *Prionastræa crassisepta*. The molluscan part of this fossil was erroneously identified by me in Prof. Gregory's paper as *Modiola Ferreti*, a species described by Dr. A. T. de Rochebrune<sup>1</sup> from the Antalo Limestones of Abyssinia, and supposed by that author to be of Neocomian age. Unfortunately, a very feeble description was given of the species, and unaccompanied by figures. It would appear, however, from the obscure nature of the Somaliland specimen, of which the crypts only are seen, that the cavities are more cylindrical than those from Abyssinia, their diameter measuring 12 millimetres. Beyond this there are no decided characters to speak of, although the lithological aspect of the specimens corresponds with other examples of the Lower Limestone fossils in the collections under description.

Locality.—Dobar, south of Berbera.

Collector.—Mrs. Lort-Phillips. [B.M.—L. 14928.]

Matrix.—Creamy-white limestone, equivalent to the 'Dobar Limestone' of Prof. Gregory.

#### LUCINA cf. GIGANTEA, Deshayes. (Pl. XX, fig. 3.)

*Lucina gigantea*, Deshayes, 'Description des Coquilles Fossiles des Environs de Paris' vol. i (1825) p. 91 & pl. xv, figs. 11–12.

*Pseudomiltha gigantea*, Fischer, 'Manuel de Conchyliologie' fasc. xi (1887) p. 1144.

*Lucina (Miltha) gigantea*, Gregorio, 'Monogr. Foss. Eocéniques (Parisien) de Mont Postale' Ann. Géol. Pal. Palerme, pt. xiv (1894) p. 35 & pl. vii, figs. 208–216.

<sup>1</sup> 'Mission G. Révoil aux Pays Comalis: Observations Géol. & Paléont.' 1882, p. 10 [*Lithodomus Ferreti*].



*Lucina gigantea*, Gregorio, 'Monogr. Faun. Eocenica Ronca' Ann. Géol. Pal. Palerme, pt. xxi (1896) pp. 94, 95 & pl. xvi, figs. 4-10; P. Oppenheim, Palæontographica, vol. xliii (1896) p. 152 & *ibid.* vol. xxx, pt. iii (1903) p. 129.

This specimen consists of a large but rather rough limestone-cast with compressed valves, related probably to this species. The adductor-scar markings are well defined, and the pallial line can be seen for some distance in the ventral region accompanied by some fine vertical striations. There is also a strong indication of the long, ligulate, anterior adductor-scar on the lateral face of the right valve, which is of rather crescentic shape. Large forms of Lucinidæ are very characteristic of the Eocene Period, being frequently found in the Paris-Basin area; in the neighbourhood of Ronca and Monte Postale (Italy); and in the Nummulitic rocks of Egypt and India. Another species, with which the specimen from Somaliland may be compared, attains an even larger size than *gigantea*: this is the *Lucina corbarica*, var. *regularis* of Leymerie,<sup>1</sup> which belongs to the Ypresian stage of the Eocene,<sup>2</sup> situated immediately below the Lutetian; but that species possesses much more convex valves, although somewhat similar in general contour. Limestone-casts of *L. corbarica*, var. *regularis* are found in the Lower Eocene deposits of Farafra, in the Libyan Desert of Egypt.

#### DIMENSIONS IN MILLIMETRES.

Umbono-ventral .....	=85	Maximum convexity with closed valves .....	=33
Antero-posterior .....	=90		

Locality.—Garrasgooi, 5 miles south-west of Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Limestone occurring below the more cherty beds.

LUCINA cf. THEBAICA (Zittel), Oppenheim. (Pl. XX, figs. 4 & 5.)

*Lucina thebaica*, Zittel, Palæontographica, vol. xxx, pt. i (1883) pp. 100, 102, etc. (list-name only; species neither figured nor described); P. Oppenheim, *ibid.* pt. iii (1903) p. 128 & pl. xiii, figs. 3-3 a.

This species of shell, although known under Zittel's list-name of *Lucina thebaica* since 1883, has only just been figured and described by Dr. Oppenheim. It is of common occurrence in Egypt, and characterizes the Middle Suessonian or the 'Libysche Stufe' of Zittel. The majority of the specimens that have come under my observation have a greater antero-posterior measurement than umbono-ventral, although Dr. Oppenheim's figures represent a shell having almost equal measurements.

The specimen from Somaliland is not so ventricose as those from Egypt, but it has much the form of this species, besides possessing similar subcentral beaks, and a sculpture showing indistinct concentric lines as well as straight longitudinal striations radiating from the summits, a character so frequently seen in members of the Lucinidæ. Both valves (closed) are represented in the specimen

<sup>1</sup> 'Mém. sur le Terrain à Nummulites des Corbières, etc.' Mém. Soc. Géol. France, ser. 2, vol. i (1846) pt. ii, p. 361 & pl. xiv, fig. 5.

<sup>2</sup> A. de Lapparent, 'Traité de Géologie' 4th ed. (1900) p. 1435.

described; the right shows the sculpture and general configuration, while the other valve exhibits the cast with the muscular-scar impressions, pallial line, and radial striations spreading down from the umbonal area. It certainly bears a very close relationship to some forms from Thebes in Egypt, preserved in the British Museum.

There is a second specimen of this shell which is entirely a cast and also with closed valves, exhibiting the usual markings as previously observed.

DIMENSIONS IN MILLIMETRES.

Umbono-ventral .....	=60	Convexity (valves closed) .....	=25
Antero-posterior .....	=73		

Locality.—Garrasgooi, 3 miles south-west of Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Limestone occurring below the more cherty limestone-beds, containing foraminifera, such as *Operculina*, etc. (see § G in the Notes on the Foraminiferal Structures, p. 176).

**LUCINA cf. MENARDI, Deshayes. (Pl. XXI, fig. 8.)**

*Lucina Menardi*, Deshayes, 'Description des Coquilles Fossiles des Environs de Paris' vol. i (1825) p. 94 & pl. xvi, figs. 13-14.

*Lucina Menardi* (?), Bellardi, 'Catal. Foss. Nummulitici d'Egitto' Mem. R. Accad. Sci. Torino, ser. 2, vol. xv (1855) p. 188.

This specimen consists of a well-preserved fragment of a Lucini-form shell with large subventricose valves, showing fairly-regular concentric striations and a portion of the postero-lateral depressed area. Indications of the ligament are also present in the dorsal region, although beyond the summits in the anterior direction the shell is fractured and all further characters are wanting. Judging from Deshayes's figures of this species, the present specimen appears to resemble it very closely. It differs from *Lucina gigantea* in possessing the well-defined area of the posterior region.

DIMENSIONS IN MILLIMETRES.

Umbono-ventral .....	=65	Maximum convexity (valves closed) .....	=30

Bellardi has doubtfully recorded the occurrence of this species in the Eocene formation of Egypt; it was originally described from the Middle Eocene of France.

Locality.—Garrasgooi, 5 miles south-west of Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Sandy-limestone occurring below the more cherty limestone-beds, with a reddish tinge.

**FIMBRIA cf. LAMELLOSA (Lamarck). (Pl. XXI, fig. 9.)**

*Lucina lamellosa*, Lamarck, Ann. Mus. Hist. Nat. Paris, vol. vii (1806) p. 237, & vol. xii (1808) p. 458 & pl. xlii, fig. 3.

*Corbis lamellosa*, Deshayes, 'Description des Coquilles Fossiles des Environs de Paris' vol. i (1824) p. 88 & pl. xiv, figs. 1-3.

*Fimbria lamellosa*, Frauscher, Denkschr. d. k. Akad. d. Wissensch. Wien, vol. li (1886) pt. ii, p. 172.

This fossil consists of a fragmentary impression of a longi-

tudinally oval-shaped valve, belonging in all probability to the genus *Fimbria*. It exhibits a regular series of equidistant oval costæ with intervening broad sulcations, which are marked by closely-set and fine transverse striæ. Only about half the valve is preserved, and this only as an impression in the limestone-matrix; yet its sculpture is of interest, as suggesting affinities with *Fimbria lamellosa* of Lamarck—a familiar Eocene shell found in Europe, Northern Africa (Egypt, etc.), Asia Minor, etc.

The original umbono-ventral measurement of the specimen must have been about 40 millimetres, and the antero-posterior about 60 mm. The posterior side appears to bear a slightly-excavated narrow and elongate area (as seen in a wax-squeeze), which recalls a character more suggestive of *Lucina* than *Fimbria*, and therefore the present identification of this specimen must be more or less provisional.

Locality.—Garrasgooi, 5 miles south-west of Upper Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—The upper or more cherty limestone-beds, showing a reddish tinge. The rock contains *Operculina* and other foraminifera (see § F in the Notes on the Foraminiferal Structures, p. 176).

### (c) Echinoidea.

#### SCHIZASTER sp.

A few remains of *Schizaster* are represented in these collections, one being an entire specimen, though much worn and without properly-detailed characters. Dr. F. A. Bather is inclined to refer them all to one species; he states that this

‘undoubted *Schizaster* is enough to prove the Tertiary age of this rock, but the ornament and contour of the specimens are scarcely preserved well enough to enable the species to be determined with certainty.’

Localities.—Top of Garrasgooi Mountain, at about 5200 feet above sea-level, 3 miles south-west of Upper Sheikh; Main Golis, 2 miles south-west from Sheikh Camp; and near Berbera.

Collectors.—Major R. G. Edwards Leckie and Dr. Donaldson Smith.

#### LINTHIA (?).

Another echinoid has been referred doubtfully to the genus *Linthia* by Dr. F. A. Bather, with the following remark:

‘It is so worn and crushed, and the actinal surface so obscured by hard matrix, which I have not succeeded in removing, that closer identification is not possible on the present evidence.’

A horizontal section of a small Rotaline is seen, on a fragment of matrix attached to the test of this specimen.

Locality.—Top of Garrasgooi Mountain, 5200 feet above sea-level, south-west of Sheikh.

Collector.—Major R. G. Edwards Leckie.

Matrix.—A cream-coloured limestone.

## (d) Actinozoa (Corals).

## CALAMOPHYLLIA AYLMERI, Gregory.

*Calamophyllia Aylmeri*, Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 31 & pl. i, fig. 3.

Major Leckie's collection contains a remarkably-good example of this coral in the cherty limestone.

Localities.—Near Uradu, north of the foot of the Rugga Pass; about 4 miles south of Camp, Upper Sheikh, elevation over 5000 feet.

Collectors.—Mrs. Lort-Phillips and Major R. G. Edwards Leckie.

Matrix.—Cherty limestone (=the Uradu Limestone of Prof. Gregory), coloured externally a reddish-brown, containing *Operculina complanata* (see § A in the Notes on the Foraminiferal Structures, p. 175).

## PRIONASTRÆA sp.

Among Dr. Donaldson Smith's specimens is a silicified coral resembling *Prionastræa crassisepta* of Gregory. The calicular details are somewhat obscure, but at the base individual corallites are seen to be longitudinally costated with closely-packed beaded lines, a character not mentioned in the original description, and therefore this specific name is not applicable to the present specimen.

Locality.—Near Berbera.

Collector.—Dr. Donaldson Smith.

Matrix.—Cherty limestone, with a reddish tinge.

## GONIOPORA PARKINSONI (Gregory).

*Litharæa Parkinsoni*, Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 37 & pl. ii, figs. 13-14.

*Goniopora somaliensis prima*, H. M. Bernard, 'Catal. of the Madreporarian Corals in the British Museum (Natural History)' vol. iv (1903) pp. 154, 155, & 195.

There is a fairly well-preserved example of this coral in the Leckie collection, exhibiting portion of a subcylindrically-branched corallum, having a length of 40 millimetres and a maximum diameter of rather more than 30 mm. The corallites are broad and with shallow calices, and in every way they conform to the characters pointed out in the original description. Mr. Bernard, in the British Museum Catalogue above quoted, has called attention to this species, and regards it as belonging to the genus *Goniopora*, on account of that generic name having priority over *Litharæa*, a view which is adopted here. Prof. Gregory's specific name of *Parkinsoni* should, however, be retained, not only because it was the first used to designate this coral, but because it is not advisable to favour the trinomial system of nomenclature suggested by Mr. Bernard.

Localities.—Above the Miriya Pass and around God-la-Yareh, south of Bur Dab (type); top of Garrasgooi Mountain, at an elevation of 5200 feet, 3 miles south-west of Upper Sheikh.

Collectors.—Mr. F. B. Parkinson (type) and Major R. G. Edwards Leckie.

Matrix.—Cherty limestone, with external reddish coloration.

#### DENDRACIS sp.

*Dendracis* sp., Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 38.

Among Major Leckie's specimens is a fragment of a *Dendracis* which agrees with the specimen described by Prof. Gregory, and it is interesting to note it from another locality in Somaliland.

Localities.—South of Bur Dab (type); Main Golis, 2 miles south-west of Sheikh camp.

Collectors.—Mr. F. B. Parkinson and Major R. G. Edwards Leckie.

Matrix.—Cherty limestone, coloured a reddish-brown.

#### IV. NOTES ON THE FORAMINIFERAL STRUCTURES IN THE TERTIARY LIMESTONES OF SOMALILAND.

The prevailing organism in the Tertiary limestones of Somaliland is *Operculina*, most probably of the species *complanata*, as understood by W. B. Carpenter, W. K. Parker, & T. R. Jones.<sup>1</sup> Several vertical sections of this form show the bossed character of the margin, as well as the great thickness of the wall of the penultimate chamber, when compared with that of the outer volution.

There is an apparent absence of Nummulites in all the sections that have been examined, but other genera are observable, especially *Amphistegina*, trochoidal Rotulines, *Textularia*, *Biloculina*, *Miliolina*, and *Globigerina*. An Orbitoid is also present, possessing rectangular chambers in the median plane, which is recognized as *Discocyclina* cf. *dispana* of J. de C. Sowerby, a species originally described from the Nummulitic deposits of Cutch.<sup>2</sup> It is allowed by most authorities<sup>3</sup> on the Foraminifera, that Orbitoids with rectangular chambers are characteristic of the Eocene Period; this organism is, therefore, of considerable importance in the determination of such an horizon among the Somaliland Limestones.

The following list includes the principal foraminifera seen in a series of microscope-slides of the Somaliland Limestones, Mr. Richard Holland having kindly assisted me in the various determinations. The slides are lettered from A to R.

#### A. *Operculina complanata* (Defrance) accompanying *Calamophyllia Aylmeri*, Gregory.

Locality.—Hill about 4 miles south of Camp, Upper Sheikh, at an elevation of over 5000 feet.

Collector.—Major R. G. Edwards Leckie.

Matrix.—Cherty limestone, stained externally a reddish-brown.

<sup>1</sup> 'Introduction to the Study of the Foraminifera' (Ray Soc.) 1862, p. 255 & pl. xvii, fig. 11.

<sup>2</sup> Trans. Geol. Soc. ser. 2, vol. v (1840) pl. xxiv, fig. 16 = *Lycophris dispanus*.

<sup>3</sup> See Ch. Schlumberger, Bull. Soc. Géol. France, ser. 4, vol. iii (1903) p. 273.

- B. *Discocyclus*, possibly *dispana* (J. de C. Sowerby), accompanying the large *Gryphaea* sp.  
Same locality, collector, and matrix as A.
- C. *Operculina* and *Amphistegina* associated with large *Gryphaea* sp.  
Same locality, collector, and matrix as A and B.
- D. *Operculina complanata* (Defrance), showing examples of the bossed margins, etc., associated with an indeterminable lamellibranch.  
Locality.—Top of Garrasgooi Mountain, south-west of Sheikh.  
Collector.—Major R. G. Edwards Leckie.  
Matrix.—Cream-coloured cherty limestone.
- E. *Operculina*, *Miliolina*, and possibly *Amphistegina*, accompanying a compound coralliferous organism showing obscure internal structure.  
Locality.—Top of Garrasgooi Mountain, 5200 feet above sea-level, south-west of Sheikh.  
Collector.—Major R. G. Edwards Leckie.  
Matrix.—Cream-coloured cherty limestone, slightly tinged with red.
- F. *Operculina*, a trochoidal Rotaline, etc., associated with *Fimbria* cf. *lamellosa*.  
Locality.—Garrasgooi, 3 miles south-west of Upper Sheikh ; same collector and matrix as E.
- G. *Textularia* and *Operculina*, found in the matrix of *Lucina* cf. *thebaica*.  
Same locality, collector, and matrix as F.
- H. *Amphistegina*, *Operculina*, and *Globigerina*.  
Locality.—Near Berbera.  
Collector.—Dr. Donaldson Smith.  
Matrix.—Cream-coloured cherty limestone.
- I. *Operculina*, *Amphistegina*, *Biloculina*, and other Miliolinæ.  
Same locality, collector, and matrix as H.
- J. *Operculina* and other organisms ; indistinct and obscure, accompanying a large indeterminable shell-fragment.  
Same locality, collector, and matrix as H & I.
- K. *Operculina*, Miliolinæ, *Textularia*, associated with a large indeterminable shell-fragment.  
Same locality, collector, and matrix as H-J.
- L. Good examples of *Operculina* associated with *Campanile somaliensis*.  
Same locality, collector, and matrix as H-K.
- M. *Operculina*, *Textularia*, Miliolinæ, and possibly *Amphistegina* ; in matrix accompanying the large Naticoid-looking shell.  
Same locality, collector, and matrix as H-L.

- N. *Operculina* and *Amphistegina* associated with the large *Conoclypeus* (?) referred to by Prof. Gregory (Quart. Journ. Geol. Soc. vol. lvi (1900) p. 42); no Nummulites observed in this matrix, as previously determined by Messrs. C. D. Sherborn & F. Chapman in Prof. Gregory's paper just quoted.

Locality.—? Kirrit, south of Bur Dab.

Collector.—Mr. F. B. Parkinson.

Matrix.—Cherty limestone, coloured reddish-brown externally.

- O. Possibly *Operculina*, *Amphistegina*, and *Globigerina*; forms rather obscure; in matrix accompanying casts of *Campanile* cf. *giganteus*, var. B.

Locality.—Dongorreh.

Collector.—Mrs. Lort-Phillips.

Matrix.—Cherty limestone, exterior deeply iron-stained.

- P. *Textularia*, *Operculina*, probably *Orbitolites*, and some Rotalinæ, associated with *Campanile* cf. *giganteus*, var. A.

Locality.—Bur Dab.

Collector.—Mr. F. B. Parkinson.

Matrix.—Cream-coloured limestone, weathering a fawn-colour.

- Q. *Discocyclina dispansa*, etc., from the type-specimen of *Columnastræa bicoronata*, Gregory, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 32 & pl. ii, figs. 7-9.

Locality.—Duban District, south of Dobar.

Collector.—Mrs. Lort-Phillips.

Matrix.—Cream-coloured limestone.

- R. *Discocyclina*, etc., from the type-specimen of *Columnastræa bicoronata*, Gregory.

Same locality, collector, and matrix as Q.

## V. LIST OF THE TERTIARY FOSSILS FROM SOMALILAND.

### GASTROPODA.

<i>Campanile</i> cf. <i>giganteus</i> (Lamarck), vars. A & B.	<i>Solarium</i> cf. <i>canaliculatum</i> , Lamarck.
<i>Campanile somaliensis</i> , sp. nov.	<i>Liotina somaliensis</i> , sp. nov.
<i>Euspira</i> cf. <i>scalariformis</i> (Deshayes).	<i>Conus</i> sp.
<i>Euspira</i> cf. <i>hybrida</i> (Lamarck).	<i>Trophon</i> (?)
	<i>Turritella</i> sp.

### LAMELLIBRANCHIA.

<i>Alectryonia</i> cf. <i>Martinsi</i> (d'Archiac).	<i>Chama</i> cf. <i>calcarata</i> , Lamarck.
<i>Gryphæa Gregoryi</i> , sp. nov.	<i>Astarte</i> (?)
<i>Gryphæa</i> sp.	<i>Lucina</i> cf. <i>gigantea</i> , Deshayes.
<i>Vulsella</i> (?)	<i>Lucina</i> cf. <i>thebaica</i> , Oppenheim.
<i>Spondylus ægyptiacus</i> , R. B. Newton.	<i>Lucina</i> cf. <i>Menardi</i> , Deshayes.
<i>Spondylus somaliensis</i> , sp. nov.	<i>Fimbria</i> cf. <i>lamellosa</i> (Lamarck).
<i>Lithophaga</i> sp.	

### ECHINOIDEA.

<i>Conoclypeus</i> (?) sp.	<i>Linthia</i> (?)
<i>Schizaster</i> sp.	

## ACTINOZOA (CORALS).

List of Prof. Gregory's new species of corals, described and figured in 1900 (Quart. Journ. Geol. Soc. vol. lvi & Proc. Roy. Soc. vol. lxxvi) as of Cretaceous age, but which must now be recognized as Tertiary:—

*Calamophyllia Aylmeri*.

*Dendracis* sp.

*Stylina* (*Cryptocænia*) *Lort-Phillipsi*.

*Stylina subtabulata*.

*Stylophora frondosa*.

*Columnastræa bicoronata*.

*Columnastræa maxima*.

*Columnastræa Phillipsiæ*.

*Favia somaliensis*.

*Cyclolites Phillipsiæ*.

*Litharæa Colæ*.

*Litharæa Parkinsoni*.

*Prionastræa crassisepta*.

*Metethmos asymmetrica*.

*Heliopora somaliensis*.

## FORAMINIFERA.

*Operculina complanata* (Defrance).

*Nummulites* (according to Sherborn & Chapman).

*Discocyclusina dispansa* (J. de C. Sowerby).

*Amphistegina*.

*Textularia*.

*Biloculina*.

*Trochoidal Rotalines*.

*Globigerina*, etc.

## EXPLANATION OF PLATES XVII-XXI.

[All figures are of the natural size, except where otherwise stated.]

## PLATE XVII.

*Campanile* cf. *giganteus*, var. A.

Fig. 1. Front view, with indications of the plicated columella on the rubbed-down surface of matrix filling the aperture.

Locality.—Bur Dab; collected by Mr. F. B. Parkinson.

[B.M.—G. 12053.]

*Campanile* cf. *giganteus*, var. B.

2. Specimen showing the four later whorls, with plications and ornamental details at the base.

Locality.—Dongorreh; collected by Mrs. Lort-Phillips.

[B.M.—G. 16071.]

3. Basal view of a smaller example of the same variety. [B.M.—G. 16072.]

Locality.—Four miles south of Camp, Upper Sheikh, at an altitude exceeding 5000 feet; collected by Major R. G. Edwards Leckie.

*Gryphæa Gregoryi*, sp. nov.

4. Dorsal view of a lower valve, showing the concave posterior area and small anterior auricle.

Locality.—Northern Somaliland; collected by Mr. F. B. Parkinson.

[B.M.—L. 12666.]

## PLATE XVIII.

*Campanile somaliensis*, sp. nov.

Fig. 1. Front view of specimen with short central canal. [ $\frac{2}{3}$  nat. size.]

[B.M.—G. 16073.]

2. Longitudinal section of another specimen, exhibiting the cylindrical axis with its plications, and the large quadrate chambers on each side.

[B.M.—G. 16074.]

Locality.—Both specimens were collected near Berbera, by Dr. Donaldson Smith.



## PLATE XIX.

*Euspira cf. scalariformis* (Deshayes).

Fig. 1. Front view of limestone-cast, showing the umbilical area and the narrow elongate aperture with its nearly-parallel sides.

2. Dorsal view of the same specimen.

Locality.—Near Berbera; collected by Dr. Donaldson Smith.

[B.M.—G. 16075.]

*Euspira cf. hybrida* (Lamarck).

3. Dorsal view of limestone-cast showing the 'ramped' character of the whorls. The curious pattern on the body-whorl represents rough cracks in the cast.

4. Basal aspect of the same specimen, showing the strong callosity.

Locality.—Bur Dab; collected by Mr. F. B. Parkinson.

[B.M.—G. 12052.]

*Solarium cf. canaliculatum*, Lamarck.

5. Dorsal view, showing part of the spire.  $\times 2$ .

6. Basal view of the same specimen.  $\times 2$ .

Locality.—Top of Garrasgooi Mountain, 5200 feet above sea-level, south-west of Upper Sheikh; collected by Major R. G. Edwards Leckie.

[B.M.—G. 16076.]

*Liotina somaliensis*, sp. nov.

7. Dorsal aspect of a specimen, showing the slightly-reflected margin of the aperture and the trellised sculpture of the shell.  $\times 2$ .

Locality.—Top of Garrasgooi Mountain, 5200 feet above sea-level, south-west of Upper Sheikh; collected by Major R. G. Edwards Leckie.

[B.M.—G. 16077.]

## PLATE XX.

*Alectryonia cf. Martinsii* (d'Archiaë).

Fig. 1. Internal view of valve, showing the ligamental region, etc.

2. External aspect of the same specimen, showing the bifurcating costæ.

Locality.—Dobar, south of Berbera; collected by Mrs. Lort-Phillips.

[B.M.—L. 14927.]

*Lucina cf. gigantea*, Deshayes.

3. Limestone-cast, showing the internal surface of the right valve, with indications of the adductor-scars and pallial markings.

Locality.—Garrasgooi, 5 miles south-west of Upper Sheikh; collected by Major R. G. Edwards Leckie. [B.M.—L. 16883.]

*Lucina cf. thebaica*, Oppenheim.

4. Right valve, showing obscure concentric and radial sculpture.

5. Umbonal aspect of the same specimen, showing the convexity of the valves.

Locality.—Garrasgooi, 5 miles south-west of Upper Sheikh; collected by Major R. G. Edwards Leckie. [B.M.—L. 16884.]

## PLATE XXI.

*Gryphæa Gregoryi*, sp. nov.

Fig. 1. Dorsal view of a lower valve of this species, showing a more produced anterior auricle than that represented in Pl. XVII, fig. 4.

2. Dorsal aspect of a similar valve of another specimen, representing the smallest example of this species that is at present known.

Locality.—Top of Garrasgooi Mountain, 5200 feet above sea-level, south-west of Upper Sheikh; collected by Major R. G. Edwards Leckie. [B.M.—L. 16885.]

*Gryphæa* sp.

Fig. 3. Section of a fragmentary lower valve of a large species, showing the thickly-laminated shell-structure.

Locality.—Hill about  $3\frac{1}{2}$  miles south-west of the Camp at Upper Sheikh; collected by Major R. G. Edwards Leckie. [B.M.—L. 16886.]

*Vulsella* (?)

4. Outer aspect of a valve, showing smooth, concentric, lamellate sculpture.

Locality.—Garrasgooi Mountain, 5200 feet above sea-level, south-west of Sheikh; collected by Major R. G. Edwards Leckie.

[B.M.—L. 16887.]

*Spondylus somaliensis*, sp. nov.

5. View of a specimen with closed valves.

6. Fragment of a larger specimen, with more distinct sculpture.

- 6 a. Costæ enlarged 4 diameters, showing the annulated ornamentation.

Locality.—Top of Garrasgooi Mountain, about 5200 feet above sea-level; collected by Major R. G. Edwards Leckie. [B.M.—L. 16888.]

*Lithophaga* sp.

7. Specimen exhibiting the crypts of *Lithophaga* (= *Lithodomus*) in a small mass of *Prionastræa crassisepta*, Gregory. [B.M.—L. 14928.]

Locality.—Dobar, south of Berbera; collected by Mrs. Lort-Phillips.

*Lucina* cf. *Menardi*, Deshayes.

8. Posterior lateral view of a fragmentary specimen, with both valves attached, showing the angulated area and concentric ornamentation.

Locality.—Garrasgooi, 5 miles south-west of Upper Sheikh; collected by Major R. G. Edwards Leckie. [B.M.—L. 16889.]

*Fimbria* cf. *lamellosa* (Lamarck).

9. View of a fragmentary valve, occurring as a limestone-impression, showing external sculpturing.

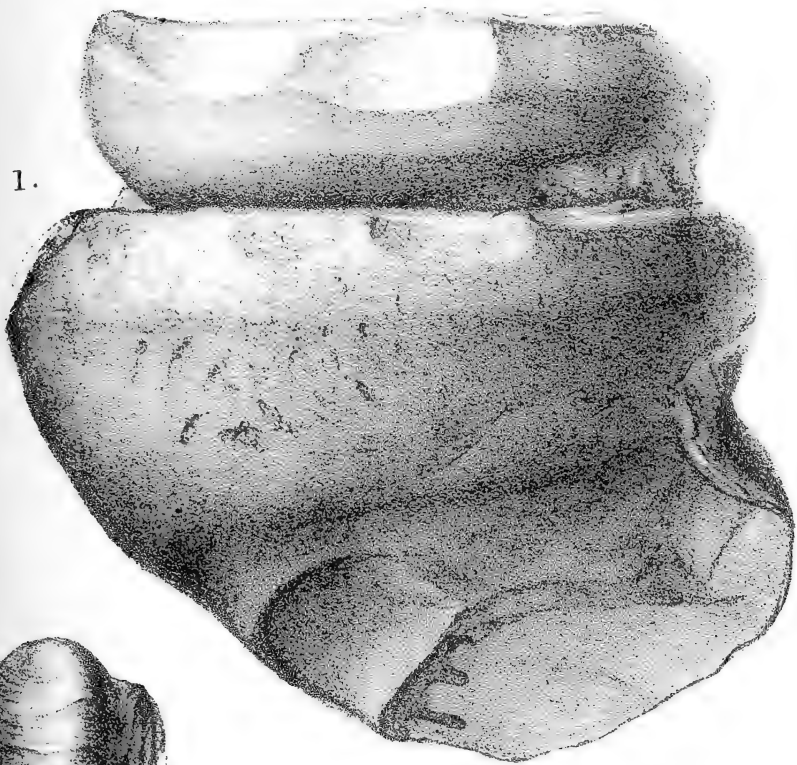
Locality.—Garrasgooi, 5 miles south-west of Upper Sheikh; collected by Major R. G. Edwards Leckie. [B.M.—L. 16890.]

## DISCUSSION.

Major R. G. EDWARDS LECKIE said that the localities from which he made his collection of fossils were at Garrasgooi and at various points along the Golis Range, west of that mountain. The Golis Range had an elevation of 5000 feet above sea-level, and formed the northern edge of the great inland plateau of Somaliland. All this plateau was covered by a bed of fossiliferous limestone, averaging, so far as he could judge, about 250 feet in thickness. In the Guban, or Maritime Plain, between the plateau and the coast, the limestones which occurred at the Eilo Range and Bihendola were, in the opinion of those who had examined the fossils, of Jurassic age. He had not observed Tertiary limestones in the Maritime Plain.

The AUTHOR thanked Major Leckie for his remarks, and the Fellows present for their reception of his paper.

1.



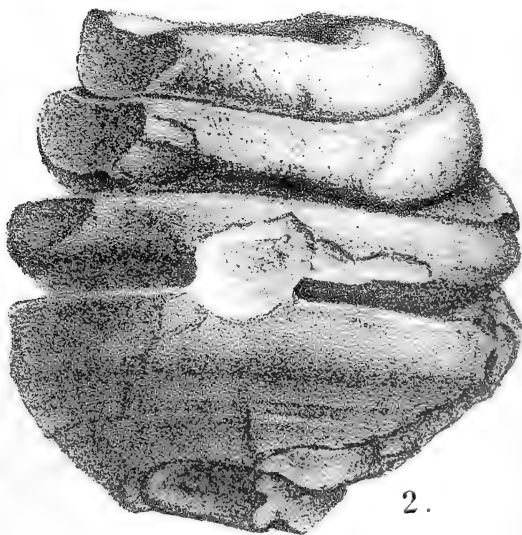
4.



3.



2.

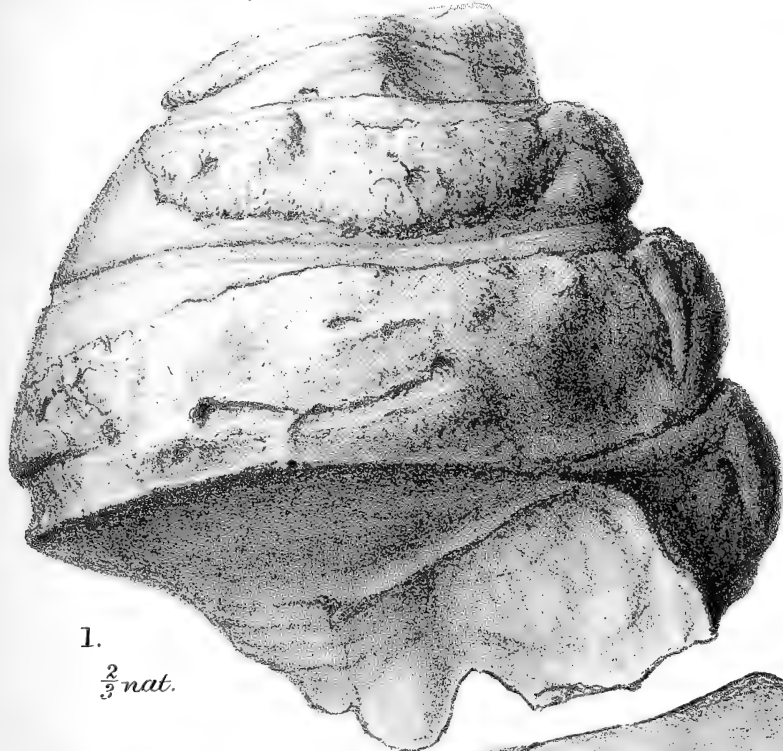


P. Highley del et lith.

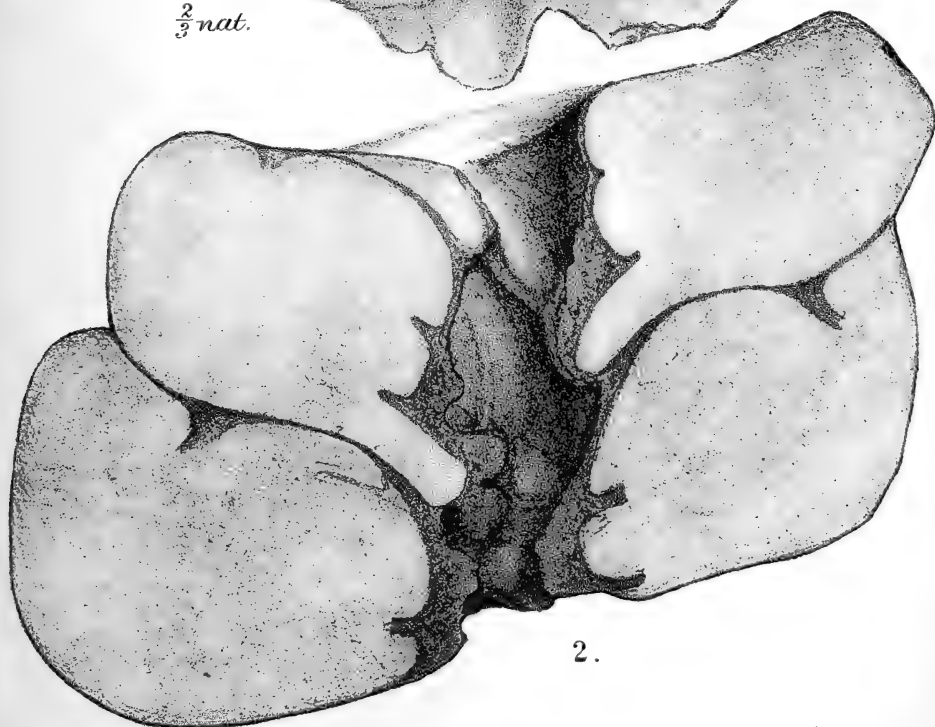
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EOCENE SHELLS FROM SOMALILAND.





1.  
 $\frac{2}{3}$  nat.



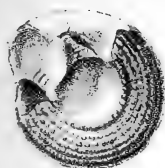
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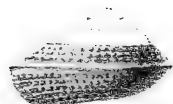
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EOCENE SHELLS FROM SOMALILAND.



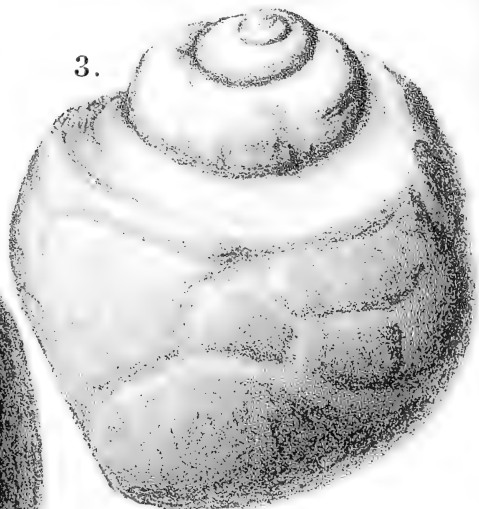


6.x2

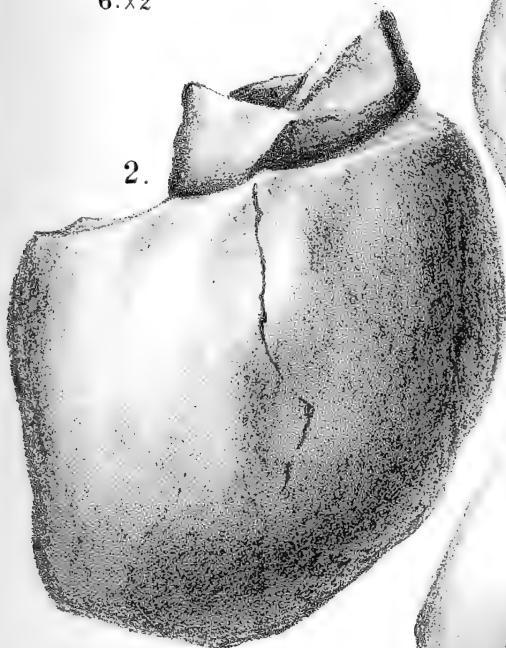


5.x2

3.



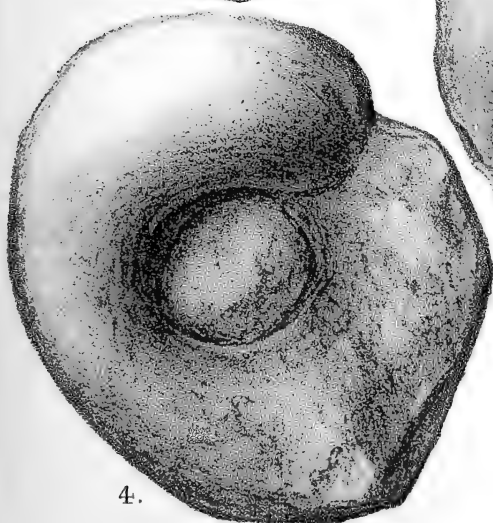
2.



1.



4.



7.x2



P. Highley del. et lith.

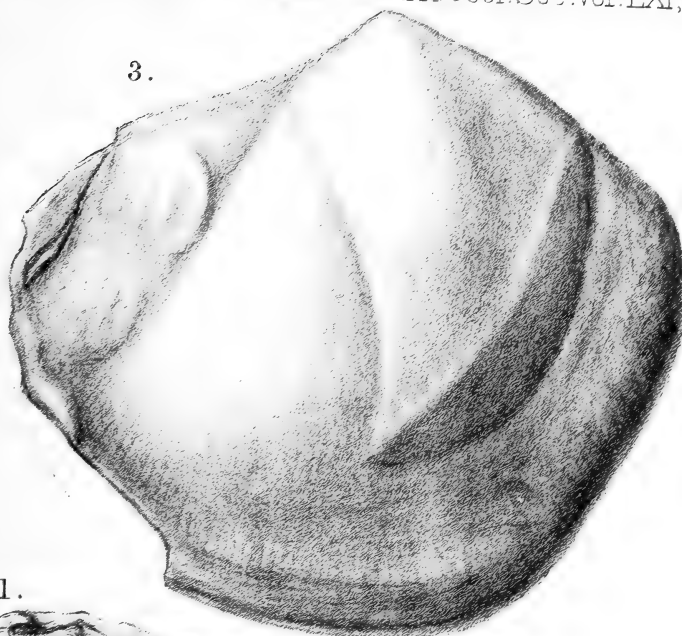
Mintern Bros. imp.

Eocene Shells from Somaliland.

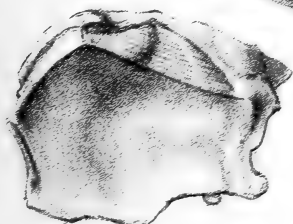




3.



1.



2.



4.



5.

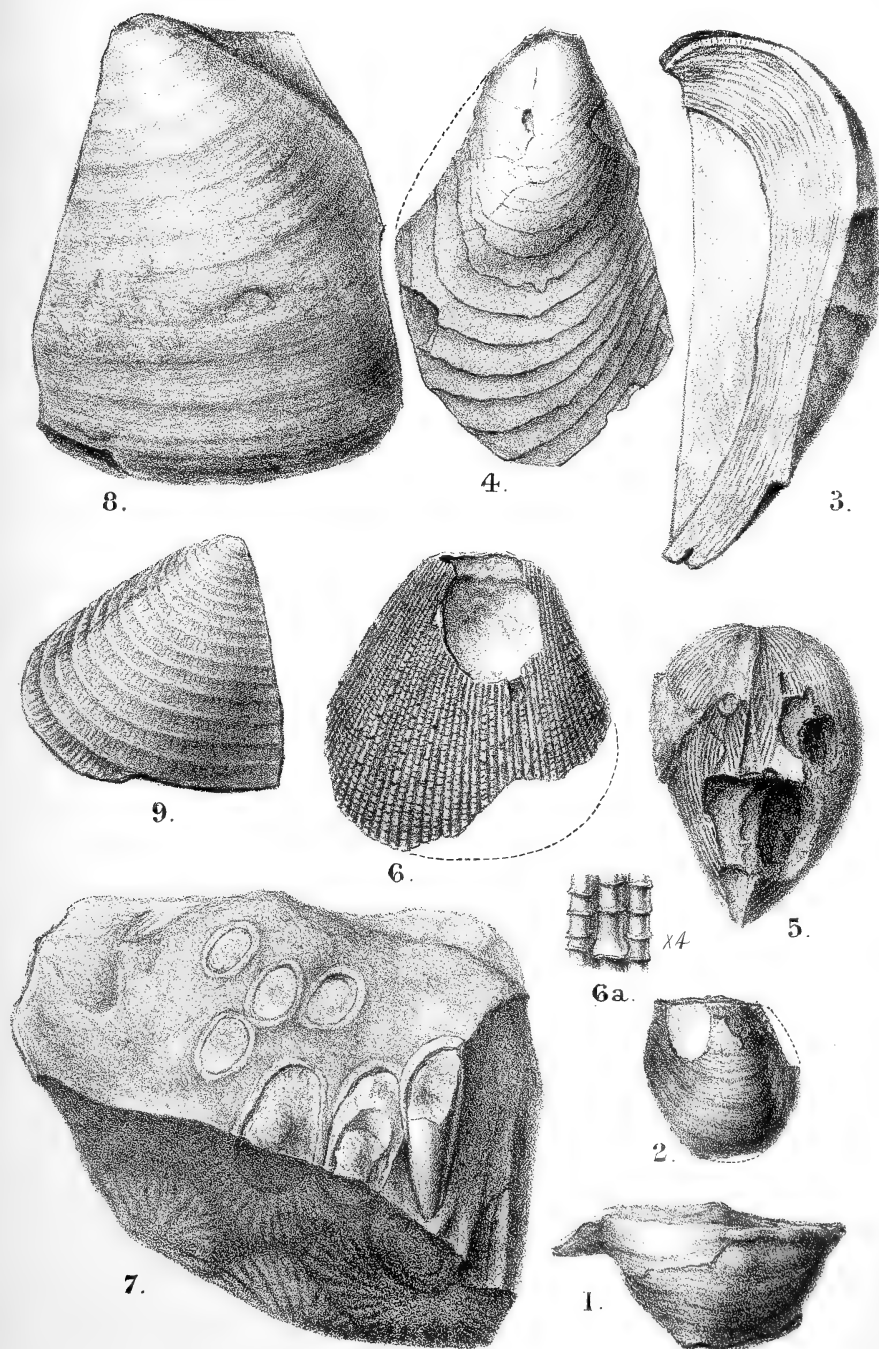


P. Highley del. et lith.

Minterm. Brocas.

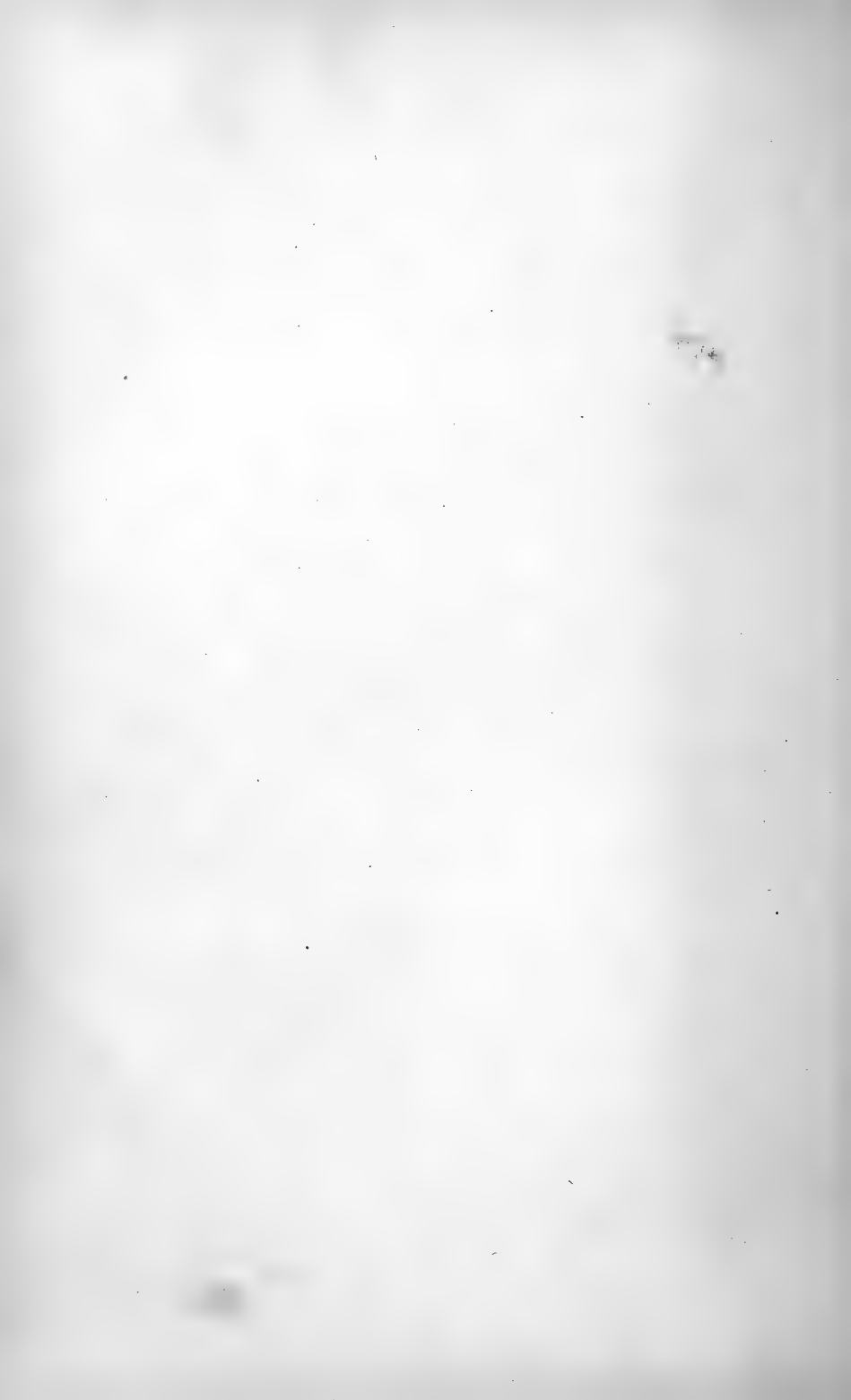
Eocene Shells from Somaliland.





P. Highley del. et lith.

Mintern Bros. imp.



11. *The PALÆONTOLOGICAL SEQUENCE in the CARBONIFEROUS LIMESTONE of the BRISTOL AREA.* By ARTHUR VAUGHAN, B.A., D.Sc., F.G.S. (Read June 8th, 1904; rearranged, and additional matter incorporated, October 1904.)

[PLATES XXII-XXIX.]

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I. INTRODUCTION.

THIS paper deals with the fossil sequence in the Carboniferous Limestone of the Bristol area, and with the possibility of dividing that system into a series of palæontological zones.

The general geology of the area has been most luminously expounded by Prof. Lloyd Morgan in the series of papers which he has contributed to the Proceedings of the Bristol Naturalists' Society, and to these I make constant reference. I am thus able largely to dispense with detailed accounts of topography and lithology, which would otherwise interrupt seriously the palæontological discussion.

Mr. E. B. Wethered has contributed a most instructive paper Q. J. G. S. No. 242.

'On Insoluble Residues obtained from the Carboniferous-Limestone Series at Clifton,'<sup>1</sup> and it is with his lithological divisions that I have mainly correlated the palæontological zones suggested in this paper.

To the late Mr. W. W. Stoddart<sup>2</sup> we owe the first attempt to compile a list of the fossil contents of the beds in the Avon Section. I have drawn up a complete analysis of his observations, so far only as the Corals and Brachiopods are concerned; this will, for convenience, follow immediately upon the detailed account of my own observations on the Avon section.

For my purpose, it is obvious that the essential desiderata are good exposures, the relative stratigraphical position of which is unquestionable. Exposures which satisfy these two conditions are to be found in several parts of the Bristol area, and, from them, the determination of the faunal sequence is merely a matter of accurate observation and careful tabulation.

Since every fossil that is recorded in the following lists was noted down at the instant at which it was observed, while all specimens which presented any difficulty in determination were extracted as completely as possible and carefully re-examined at leisure, I may claim that these lists are absolutely reliable, provided that each name presents exactly the same idea to those who read it, as it does to me in writing it.

This is always a very necessary reservation to bear in mind, in the interpretation of lists of fossils from the Carboniferous Limestone. The most familiar specific names usually cover so many mutations and varieties, that they convey no exact information, and, in consequence, comparisons instituted, in reliance on such lists, are apt to be very unconvincing. The indefiniteness of the well-known specific names was well pointed out by Prof. Watts, in his presidential address to the Geological Section of the British Association, at the Southport meeting in 1903.<sup>3</sup>

In order to secure the requisite definiteness, I have appended a series of photographs (Pls. XXII-XXVI) which not only illustrate the new specific names that I have here introduced for the first time, but also convey the precise sense in which some of the well-known specific names are employed in this paper. With this addition, I believe that I may fairly claim for this paper:—

- (1) That it is an accurate record of the faunal sequence throughout the Bristol area.
- (2) That, by means of the plates, the majority of the specific names convey the precise meaning which they are intended to bear.

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<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlv (1888) p. 186.

<sup>2</sup> Proc. Bristol Nat. Soc. n. s. vol. i (1875) p. 313.  
Rep. Brit. Assoc. 1903 (Southport) p. 643.

Throughout the Carboniferous Limestone of the Bristol area, Corals and Brachiopods play the leading parts, and it is with these two groups alone that this paper deals.

The Bryozoans are, nevertheless, of considerable service in the field, since they are abundant and undoubtedly obey a fixed law of vertical succession; but their zonal distribution must be worked out by those who possess a special knowledge of this difficult group.

Since no system of zones, founded entirely upon a purely-palæontological basis, has previously been suggested for the Carboniferous Limestone, my task was rendered easier, in that I had merely to adopt that system which best co-ordinated the faunal succession in the Bristol area. Such a system, deduced from the examination of a single area and founded entirely upon two fossil-groups, cannot of course presume to be more than a preliminary attempt to deal with a large and complicated problem; but it may serve as part of the scaffolding, by means of which a system of general application will ultimately be built up. In order that the suggested divisions may have more than a merely-local value, I have selected genera for the zonal indices and species-groups for the subzonal indices.

The tendency of recent palæontological work is to make the species the unit of division, and to include in its definition every observable property. The necessary result of such minute definition is, undoubtedly, to ensure that the same name always conveys precisely the same meaning; but, on the other hand, it tends to confine each species to a limited area, as well as to a limited horizon. Hence, a perfectly-defined species is not likely to be of great value as a zonal or subzonal index.

A gens or species-group may be considered to be the aggregate of all the species which possess, in common, a large number of essential properties, and are continuously related either in space or time. I had originally used the term *circulus* in the sense here defined; but, although Prof. Gregory certainly employs the term in this sense,<sup>1</sup> I agree with Dr. Bather that this is not the original meaning which he attached to the term. I consequently employ *circulus* only in the sense explained by Dr. Bather, and suggest the term *gens* to convey the meaning of a species-group as here defined. (See Discussion, pp. 306-307.)

It is immediately obvious that such a definition has no absolute exactness, for it depends entirely upon the conception of what are essential properties, and also upon how few such common properties may be considered sufficient to allow of two species being grouped in the same species-group. There is not, however, any great difference of opinion as to the essential similarity of two species; the danger is, rather, that two species, evolved along

<sup>1</sup> 'Brit. Mus. Catal. of the Jurassic Bryozoa' 1896, p. 27.

different lines and at very different dates in the earth's history, may be included in the same species-group. Two forms which are essentially similar and occur on the same relative horizon, but in distant localities, may with great probability be referred to the same species-group. For example:—*Spirifer tornacensis*, of the Lower Tournaisian of Belgium, is essentially similar to *Sp. aff. clathratus* of the Bristol area, which occurs at the same horizon; consequently, these two species may be referred to the same species-group.

On the other hand, a form resembling *Productus Martini*, which occurs in the uppermost zone of the Carboniferous Limestone in the Bristol area, has almost certainly been immediately evolved from ancestors of the type of *Pr. Cora*, and is in no way a survivor of the form here denoted by *Pr. cf. Martini*, which characterizes the lower part of the Carboniferous-Limestone Series in the Bristol area. These two forms are, however, easily distinguished, and should consequently receive distinct specific names; but, though similar, they cannot be referred to the same species-group, since their lines of evolution are totally distinct.

The use of 'aff.' before a specific name will imply that the fossil under consideration and that with which it is compared belong to the same species-group.

The use of 'cf.' before a specific name merely denotes a certain degree of similarity, but does not necessarily imply genetic relation.

Mutations are strictly the time-variants of a gens, but I include, also, space-variants under the same term, for no sharp distinction can possibly be drawn between the two types of variant. The mutations of a gens usually mark the points of convergence of that gens with cognate gentes.

In the Bristol area, the Corals are the most valuable genera as zonal indices, for the following reasons:—

- (1) Corals are abundant in all parts of the area, and almost throughout the whole of the Carboniferous Limestone.
- (2) The genera are easily distinguished, by the aid of sections, even in small fragments.
- (3) They have usually well-defined ranges.
- (4) It seems almost certain that *Zaphrentis*, *Caninia*, *Lithostrotion*, *Clisiophyllum*, and *Lonsdalia* are stations on an unbroken line of evolution; and it may also be possible to demonstrate that *Caninia*, *Cyathophyllum* of the type of *C. φ*, *Cyathophyllum* of the type of *C. Murchisoni*, and *Cyathophyllum* of the type of *C. regium* are corresponding stages in evolution along another radius.

With regard to (4), it is clear that any system of zonal indices, in which each index is the result (either entire or partial) of evolution from the one which precedes, has a special value, from the fact that the relative order is necessarily the same for all localities.



If, however, it is found that the zonal indices succeed each other in the same order in two distinct localities, and it is also found that a number of other fossils are common to the two localities, it cannot be assumed as a necessary deduction, and is not a demonstrated fact, that the fossils associated with any particular index in the one place, will be again associated with that index in the second place, or will be distributed in the same way throughout its zone. Even in a small area, there is, in the case of two widely-different classes of organisms, such as Corals and Brachiopods, a small relative displacement of the one group upon the other, at different points of the area.

For example, if, in the Burrington, Avon, and Tytherington sections, we register the first occurrence of *Caninia*, in terms of the brachiopod-sequence at each locality, the event is found to occur at Burrington in the *resupinata*-subzone, in the Avon section just above that subzone, and at Tytherington in the *laminosa*-subzone: thus demonstrating a retardation of the coral-sequence upon the brachiopod-sequence, as we proceed from south to north.

If the amount of relative displacement of one group upon another were accurately charted at different points of any area, it would be possible to estimate the relative acceleration of the one group upon the other, both in direction and amount, and, hence, to deduce the probable association of fossils in a distant locality.

At an early stage it was found necessary, for purposes of accurate registration and co-ordination, to adopt a series of zonal indices. Those genera, consequently, are selected as zonal indices, the abundance of which throughout definite portions of the series has forced itself upon my attention, when working in the field.

It was ascertained that there was usually a certain interval, of greater or less extent, in which the indices of two successive zones were found associated together. The faunal overlaps of zones form very definite horizons, and I have consequently designated them Horizon  $\alpha$ ,  $\beta$ , etc.

A series of subzonal indices was next adopted, to designate the parts of a zone, whenever a marked change of fauna naturally called for the subdivision of a zone. For this purpose species-groups were employed, and the particular groups selected have been chosen for one of two reasons:—

- Either (1) they have their maximum development within the portion which they were selected to indicate;
- or (2) they are survivors of an earlier fauna, occurring commonly among the members of a later facies.

It is important, however, to emphasize the fact that the zonal and subzonal indices are merely employed to connote special faunal aggregates, so that the presence of a zone can be definitely asserted, even though the index of that zone has not been discovered.

The series of zones and subzones is as follows :—

Zones.	Subzones and Horizons.
VISÉAN. DIBUNOPHYLLUM.  SEMINULA .....	<div style="text-align: center;">ε</div> <div style="display: flex; justify-content: space-around;"> <div style="text-align: left;">{ (D<sub>2</sub>) <i>Lonsdalia floriformis</i>.</div> <div style="text-align: left;">{ (D<sub>1</sub>) <i>Dibunophyllum</i> θ.</div> </div> <div style="display: flex; justify-content: space-around;"> <div style="text-align: left;">{ (S<sub>2</sub>) <i>Productus Cora</i> (mut. S<sub>2</sub>).</div> <div style="text-align: left;">{ (S<sub>1</sub>) <i>Productus semireticulatus</i> (mut.).</div> </div>
TOURNAISIAN.  SYRINGOTHYRIS...   ZAPHRENTIS .....   CLEISTOPORA .....   ( <i>Modiola</i> -phase) ...	<div style="text-align: center;">δ</div> <div style="display: flex; justify-content: space-around;"> <div style="text-align: left;">(C) <i>Syringothyris</i> aff. <i>laminosa</i>.</div> <div style="text-align: right;">(CANINIA-Zone.)</div> </div> <div style="text-align: center;">γ</div> <div style="display: flex; justify-content: space-around;"> <div style="text-align: left;">{ (Z<sub>2</sub>) <i>Schizophoria resupinata</i>.</div> <div style="text-align: left;">{ (Z<sub>1</sub>) <i>Spirifer</i> aff. <i>clathratus</i>.</div> </div> <div style="text-align: center;">β</div> <div style="display: flex; justify-content: space-around;"> <div style="text-align: left;">{ (K<sub>2</sub>) <i>Spiriferina octoplicata</i>.</div> <div style="text-align: left;">{ (K<sub>1</sub>) <i>Productus bassus</i>.</div> </div> <div style="text-align: center;">α</div> <div style="display: flex; justify-content: space-around;"> <div style="text-align: left;">(M) <i>Modiola lata</i>.</div> </div>

The correlation of the faunal divisions (enumerated in the foregoing table) with the lithological divisions previously in use, is fully set out in the detailed description of the Avon section (p. 188).

The discussion of the reasons for choosing the zonal indices and for dividing the whole Carboniferous-Limestone Series into two great divisions can only be undertaken after the detailed account of the whole area has been set out. The general scheme of this detail is sufficiently explained by the Table of Contents (p. 181).

Fig. 1.



## II. DETAILED DESCRIPTION OF CONTINUOUS SECTIONS AND ISOLATED EXPOSURES IN THE BRISTOL AREA.

### (i) Continuous Sections.

#### (a) THE AVON SECTION.

##### Tournaisian or Lower Carboniferous Limestone.

M = Zone<sup>1</sup> of *Modiola lata* (MODIOLA-Zone).

Lithological character.—Shales with subsidiary limestones, ending with a series of red limestones (Horizon a).

Former designation.—The lower portion of the Lower Limestone-Shales, ending with the 'Bryozoa-Beds.'

Where exposed in the Avon section:—

Clifton side: The cuttings on both the Avonmouth lines near Cook's Folly.

Leigh Woods side: A riverside exposure, and the cutting on the Portishead line.

Coral-fauna.—None as yet recorded.

##### Brachiopod-fauna:

Abundant.	{	<i>Cliothyris Royssii</i> .
		<i>Eumetria</i> (' <i>Retzia</i> ') sp.
Rare.	{	<i>Camarotoechia</i> aff. <i>mitcheldeanensis</i> .
		Spiriferids (fragments of
		<i>Spirifer</i> sp. and <i>Syringothyris</i> sp.).

Rare.	{	<i>Orthotetes crenistria</i> .
		<i>Leptena analoga</i> .
		And probably (see analysis of Stoddart's paper, p. 201):—
		<i>Lingula</i> sp.
		( <i>Discina</i> ) sp.
		<i>Chonetes</i> cf. <i>hardrensis</i> .

##### Other groups:

##### Lamellibranchia.

*Modiola lata* and *M.* sp.

*Sanguinolites* spp.

##### Gasteropoda.

*Murchisonia* spp.

*Bellerophon* sp.

##### Bryozoa.

*Rhabdomeson* cf. *rhombiferum*  
and *Rhabdomeson* sp.

Fenestellids.

##### Polychæta.

*Spirorbis* sp.

Ostracoda, several forms.

Scales of fishes and plant-remains.

Note on the definiteness of Horizon a in the Bristol area.—In so far as the brachiopod-fauna is concerned, Horizon a is characterized by:—

- (i) The occurrence of forms which become enormously abundant in the succeeding zone. Examples are:—*Orthotetes crenistria*, mut. *K*<sub>1</sub>; *Leptena analoga*; *Chonetes* cf. *hardrensis*.

<sup>1</sup> It is pointed out, at the end of this paper, that the *Modiola*-Zone had better be regarded as a shallow-water phase of the *Cleistopora*-Zone, than as a distinct zone; but the invariable occurrence of similar bathymetric conditions, wherever the Upper Old Red Sandstone is conformably overlain by the Carboniferous Limestone, renders the distinction of this phase a matter of considerable stratigraphical importance.

- (ii) The presence of forms which, in the Bristol area, are confined to the upper portion of Zone M and to Subzone K. Examples are:—*Eumetria* ('*Retzia*') spp.; *Cliothyris Royssii*; *Camarotæchia* aff. *mitcheldeanensis*.

If account be taken of the other groups:—

The rare occurrence of *Modiola lata* and of ostracods in Horizon  $\alpha$  links that horizon with Zone M.

The abundance of *Rhabdomeson* links Horizon  $\alpha$  with Zone K. Hence Horizon  $\alpha$  forms, from a palæontological point of view, a somewhat indefinite level of overlap, in which the *Modiola*-ostracod phase passes gradually into the faunal phase characteristic of the *Cleistopora*-Zone.

From a lithological standpoint, the development of the highly-characteristic red, crystalline, encrinital limestone at this level throughout the Bristol area appears to give to Horizon  $\alpha$  a definiteness which its palæontological characters scarcely warrant.

### K = Zone of *Cleistopora* aff. *geometrica* (*CLEISTOPORA*-Zone).

**Lithological character.**—This zone has the 'Palate-Bed' for its base, and includes the whole of the thick series of shales (with subsidiary limestones) which lie between that bed and the base of the massive limestones of the *Zaphrentis*-Zone.

**Former designation.**—The whole of the Lower Limestone-Shales which lie above the 'Bryozoa-Beds.'

**Where exposed in the Avon section:—**

Clifton side: Occasional exposures along the Avonmouth line, near Cook's Folly.

Leigh Woods side: The lowest beds are shown in the riverside exposure; the topmost beds are shown in Quarry 1 (see Pl. XXVII).

#### Coral-fauna:

*Cleistopora* aff. *geometrica*.

#### Brachiopod-fauna:

*Cliothyris Royssii* vars. & mut.  $\beta$ .  
*Spirifer* aff. *clathratus* & var.  
*Spiriferina octoplicata*.  
*Syringothyris* aff. *cuspidata*.  
*Eumetria* ('*Retzia*') aff. *carbonaria*.  
*Camarotæchia mitcheldeanensis*.  
*Leptena analoga*.  
*Orthotetes crenistria* (especially mut.  $K_1$ ).

*Rhipidomella* aff. *Michelini*.  
*Productus bassus*.  
*Productus* cf. *Martini*.  
*Chonetes* cf. *Buchianu*, *Ch.* cf. *crassistria*, and intermediate forms.  
*Chonetes* cf. *hardrensis*.  
*Lingula* sp.  
(*Discina*) sp.

#### Subdivisions:—

$K_1$  = Subzone of *Productus bassus* (*BASSUS*-subzone).

This includes only the lowest portion of the zone, and is characterized by the great abundance of:—

*Camarotæchia mitcheldeanensis*, *Leptena*, *Orthotetes crenistria*, mut.  $K_1$ , *Productus bassus*, and small *Chonetes*.

*Eumetria* ('*Retzia*') aff. *carbonaria*, *Productus bassus*, and *Chonetes* cf. *Buchiana* are practically confined to this subzone.

*Syringothyris* aff. *cuspidata* becomes common towards the top of the subzone; but *Spirifer* spp., *Spiriferina octoplicata*, *Rhipidomella*, and *Productus* cf. *Martini* are either absent or very rare.

## K<sub>2</sub>=Subzone of *Spiriferina octoplicata* (OCTOPLICATA-subzone).

This includes the upper and main portion of the *Cleistopora*-Zone, as well as the horizon of overlap with the *Zaphrentis*-Zone (Horizon β).

### Brachiopods:

*Leptena*, *Orthotetes*, *Chonetes* cf. *crassistria*, and *Ch.* cf. *hardrensis* are still abundant; but *Orthotetes* shows a mutational change.

*Camarotæchia mitchelleanensis* is still common, but diminished in numbers; and *Spirifer* aff. *clathratus* becomes increasingly numerous as we approach Horizon β.

*Rhipidomella*, *Productus* cf. *Martini*, and the mutation of *Cliothyris Royssii* which is characteristic of the lowest subzone of the *Zaphrentis*-Zone begin to make their appearance.

*Spiriferina octoplicata* reaches its acme at the top of this subzone.

### Corals:

*Cleistopora* aff. *geometrica* is nowhere common, but is most abundant in the upper part of this subzone.

## Z=Zone of *Zaphrentis* aff. *Phillipsi* (ZAPHRENTIS-Zone).

Lithological character.—Massive limestones, usually very encrinital.

Former designation.—The Lower Limestone (omitting the uppermost beds).

Where exposed in the Avon section:—

Clifton side: The Black Rock (see below, pp. 191–93).

Leigh Woods side: Quarries 1 & 2 (see Pl. XXVII).

### Coral-fauna:

*Zaphrentis* aff. *Phillipsi*.  
*Zaphrentis* aff. *cornucopie*.  
*Caninia cylindrica*.

*Amplexus* cf. *coralloides*.  
*Michelinia* spp.  
*Syringopora* θ.

### Brachiopod-fauna:

*Cliothyris glabristria* & mut.  
*Cliothyris Royssii* & mut.  
*Spirifer* aff. *clathratus* & var.  
*Reticularia* aff. *lineata*.  
*Spiriferina octoplicata*.  
*Syringothyris cuspidata*, muts.  
*Syringothyris* aff. *laminosa*.  
*Camarotæchia mitchelleanensis*, muts.  
*Camarotæchia* cf. *pleurodon*.  
*Leptena analoga*.  
*Schizophoria resupinata*.

*Orthotetes crenistria* (especially mut. Z).  
*Rhipidomella* aff. *Michelini*.  
*Productus* cf. *Martini*.  
*Productus semireticulatus*, muts.  
*Productus* aff. *pustulosus*.  
*Productus* aff. *Cora* mut. Z.  
*Chonetes* cf. *crassistria*.  
*Chonetes* cf. *hardrensis*.  
*Chonetes papilionacea*.

## Subdivisions:—

$\beta$  = Horizon  $\beta$ .

This includes the very lowest beds of this zone; these beds might, probably with equal truth, be considered as the very topmost beds of the preceding zone, for *Zaphrentis* and *Spiriferina octoplicata* co-occur here, while all the brachiopods pass continuously from the series below into this horizon. It is, then, a well-marked horizon of overlap, and is lettered accordingly.

I include it as the base of the *Zaphrentis*-Zone rather than as the top of the *Cleistopora*-Zone, for three reasons:—

- (a) *Zaphrentis* is first met with here, and is immediately fairly common, whereas *Cleistopora* has not been registered here.
- (b) *Cliothyris glabristria* first occurs (so far as I know) at this horizon.<sup>1</sup>
- (c) *Spirifer* aff. *clathratus* becomes extraordinarily abundant, and continues so for some time.

## Where exposed in the Avon section:—

Clifton side: The lowest part of the Black Rock (that is, the small separate quarry, which is now closed and forms part of a private estate).<sup>2</sup>

Leigh Woods side: Quarry 1.

Special faunal characters.—This horizon is only to be distinguished from the rest of the lower portion of the *Zaphrentis*-Zone by the common occurrence of *Spiriferina octoplicata*; all its other characters are exactly those which distinguish the *clathratus*-subzone.

$Z_1$  = Subzone of *Spirifer* aff. *clathratus* (*CLATHRATUS*-subzone).

[So named from the enormous abundance of the index-fossil.]

## Where exposed in the Avon section:—

Clifton side: All the beds of the Black Rock, up to the slope at the northern end of the present quarry.

Leigh Woods side: Quarry 1, and the lowest part of Quarry 2.

## Special faunal characters:—

## Brachiopods:

*Cliothyris Royssii* (mut.  $\beta$ ), *Rhipidomella*, and *Productus* cf. *Martini* reach their maxima, while *Spirifer* aff. *clathratus* and its varieties maintain their extreme abundance throughout the subzone.

*Spiriferina octoplicata*, as already stated, is rare above the lowest beds (Horizon  $\beta$ ).

*Rhynchonella mitcheldeanensis*, *Leptena analoga*, *Chonetes* cf. *hardrensis*, and *Ch.* cf. *crassistria* are abundant at certain levels.

<sup>1</sup> See note under *Cliothyris glabristria*, p. 297.

<sup>2</sup> This quarry is named 'Press's Quarry,' on the sketch-map of the Avon quarries (Pl. XXVII).

*Syringothyris cuspidata* and *Orthotetes crenistria* are abundant in those particular mutations which characterize the *Zaphrentis*-Zone.

*Cliothyris glabristria* and *Reticularia* aff. *lineata* enter, and gradually increase in abundance.

*Chonetes papilionacea* occurs rarely, for the first time, near the top of the subzone.

#### Corals:

*Zaphrentis* aff. *Phillipsi* is common in certain beds.

*Syringopora*  $\theta$  occurs rarely.

No other corals have been recorded.

$Z_2$  = Subzone of *Schizophoria resupinata* (*RESUPINATA*-subzone).

Where exposed in the Avon section:—

Clifton side: The main Black-Rock Quarry (that is, that portion of the present quarry which has been worked back to a considerable distance from the line) not including the southern end. (See Horizon  $\gamma$  and Zone C, p. 193.)

Leigh Woods side: The upper part of Quarry 2.

#### Special faunal characters:—

##### Brachiopods:

*Cliothyris Royssii*, *Spirifer* aff. *clathratus*, *Camartoechia mitchelleanensis*, *Leptena analoga*, and *Chonetes* cf. *crassistria* are nowhere common.

*Syringothyris cuspidata* and *Orthotetes crenistria* are abundant in the mutations typical of the *Zaphrentis*-Zone.

*Rhipidomella* aff. *Michelini* is common, but has passed its acme.

*Cliothyris glabristria* and *Schizophoria resupinata* reach their maxima, and are prolific.

*Chonetes* cf. *hardrensis* teems in certain beds, where it is more and more frequently associated with *Ch. papilionacea*.

*Productus* cf. *Martini* becomes rare, and is replaced by a larger form closely allied to *Pr. semireticulatus*. *Productus* aff. *Cora*, mut. *Z*, is rare.

*Syringothyris* aff. *laminosa* makes its entrance in this subzone.

#### Corals:

*Zaphrentis* aff. *Phillipsi*  
*Zaphrentis* aff. *cornucopiæ* } teem throughout the subzone,  
 and reach their maxima near the  
 top of it.

*Amplexus* cf. *coralloides* enters towards the top, and quickly attains its maximum.

*Caninia cylindrica* and *Michelinia* occur rarely in the very topmost beds.

*Syringopora*  $\theta$  is common at certain levels.



$\gamma$  = Horizon  $\gamma$ .

(The top of the *Zaphrentis*-Zone and the bottom of the *Syringothyris*-Zone.)

Where exposed in the Avon section :—

Clifton side: The southern end of the present Black-Rock Quarry.

Leigh Woods side: Towards the top of Quarry 2.

Special faunal characters :—

Brachiopods :

*Syringothyris cuspidata*, *S. aff. laminosa*, and *Orthotetes crenistria*, mts. Z and C, are common.

*Chonetes papilionacea* becomes abundant and *Chonetes cf. hardrensis* rare.

*Productus aff. semireticulatus* is occasionally found.

All the other brachiopods cited as typical of the *Zaphrentis*-Zone are rare at this horizon.

Corals :

*Michelinia* and *Amplexus* are not uncommon, but the important feature of the horizon is the co-occurrence of *Zaphrentis* and *Caninia* in remarkable abundance. The level is thus a well-marked 'horizon of overlap' of the *Zaphrentis*- and *Caninia*-Zones, and is consequently designated Horizon  $\gamma$ .

C = Zone of *Syringothyris aff. laminosa* = Lower *Caninia*-Zone. (*SYRINGOTHYRIS*-Zone.)

Lithological character.—The following rocks are met with in ascending order :

- (1) Encrinital limestones, which are appreciably dolomitic. (The *laminosa*-dolomites.)
- (2) A thick band of oolite. (The *Caninia*-Oolite.)
- (3) Shales with thick bands of dolomite and subsidiary beds of oolite (lower part only).

Former designation.—In ascending order :

- (1) Top beds of the Lower Limestone.
- (2) Gully Oolite.
- (3) Middle Shales (lower part only).

Where exposed in the Avon section :—

Clifton side :

- (1) Occurs between the Black-Rock Quarry and the Gully-path and at the base of the Gully Oolite-quarry.
- (2) Forms the main portion of the Gully Oolite-quarry.
- (3) Is exposed in the low railway-cutting between the Gully and the Great Quarry (lower part only).

Leigh Woods side :

The topmost beds of (1), (2), and the very lowest beds of (3) are seen in Quarry 3.

## Special faunal characters:—

## Brachiopods:

*Orthotetes crenistria*, mut. C, and *Chonetes* aff. *papilionacea* crowd the beds at certain levels (often the *Chonetes* passes into a strongly-convex variant, *Ch.* cf. *comoides*).

*Syringothyris cuspidata* and *Productus* aff. *semireticulatus* are met with occasionally.

*Syringothyris* aff. *laminosa*, though never actually abundant, can always be found, and is highly characteristic of the zone.

## Corals:

*Syringopora* cf. *reticulata* occurs.

*Michelinia megastoma* is not uncommon.

*Amplexus* probably occurs here.

*Zaphrentis* is seldom found, except at the base (in Horizon  $\gamma$ ).

*Caninia cylindrica* attains its maximum at the base.

NOTE.—In the Avon section the uppermost beds of this zone are unfossiliferous, so that there appears to be a remarkable palæontological break between this zone and the succeeding *Seminula*-Zone; this break is, however, partly filled in by certain beds found in neighbouring parts of the Bristol area (see under Failand and Clevedon). I shall consequently defer the necessary discussion, as to the advisability of retaining a single zone (the *Caninia*-Zone) to cover both the zone C and the subzone  $S_1$ , until a later portion of the paper (p. 260).

## Viséan or Upper Carboniferous Limestone.

S=Zone of *Seminula ficoidea* and its allies (*SEMINULA*-Zone).

Lithological and palæontological details are more conveniently set out under the separate subzones.

The essential faunal characters of this zone are the extreme abundance and the association of *Seminula* spp., *Lithostrotion Martini* (vars. & muts.), and giganteid *Producti* (including *Productus* aff. *Cora*).

The lower subzone ( $S_1$ ) is distinguished by the survival of Tournaisian forms, such as *Syringothyris* spp., *Productus* aff. *semireticulatus*, *Caninia* aff. *cylindrica*. The upper subzone ( $S_2$ ), on the other hand, is characterized by the incoming of forms which abound in the *Dibunophyllum*-Zone, such as Clisiophyllids, *Cyathophyllum Murchisoni*, *Alveolites*.

## Subdivisions:—

$S_1$ =Subzone of *Productus semireticulatus*, mut.  $S_1$ =  
Upper *CANINIA*-Zone.

## Lithological character:

- (1) Shales and thick bands of dolomite and occasional beds of oolite. Succeeded by
- (2) Massive limestones with thin shale-partings; many of these limestones are appreciably dolomitic, and are beautifully

compact in texture, with good conchoidal fracture; others are granular and encrinital.

Former designation:

(3) Middle Shales (upper part only).

(4) *Mitcheldeania*-Beds, at the base of the Middle Limestones.

Where exposed in the Avon section:—

Clifton side: The upper part of the cutting between the Gully Oolite-Quarry and the Great Quarry, and the lower third of the Great Quarry.

Leigh Woods side: The lowest beds in Quarry 4 (see Pl. XXVII).

Special faunal characters:—

Brachiopods:

*Seminula ficoidea* and its allies become extremely abundant, and are associated with prolific specimens of a giganteid *Productus* (*Pr. θ*).

*Productus semireticulatus* still occurs, and a well-marked mutation with very long spines characterizes a bed at the top of the subzone (the so-called 'longispinus'-bed).

*Productus* aff. *hemisphericus* is not uncommon.

*Syringothyris* aff. *laminosa* and *Athyris* (?) sp. occur in considerable numbers at one level.

*Orthotetes crenistria*, in a characteristic mutation, is found somewhat rarely in the upper beds, and the gens has entirely lost that predominance which is so noteworthy a feature of the Tournaisian facies.

Corals:

*Caninia cylindrica* (especially in its mutation *bristolensis*) is abundant chiefly in the upper half, and with it are associated (probably) occasional specimens of *Amplexus* and *Michelinia*.

*Syringopora* becomes common at the top in a distinct form (cf. *S. distans*).

*Lithostrotion Martini* appears early in the subzone, and, in the upper portion, whole beds are made up of this species and of one of its varieties.

*Lithostrotion basaltiforme* (var. *bristolense*) has long been known to collectors; it abounds in a few beds near the top of the subzone (one of these beds, which is stained black by petroleum, is known as the 'Aranea-Bed').

*Alveolites* sp. and *Cyathophyllum* are rare.

A characteristic bryozoan in this subzone is *Heterotrypa tumida*.

S<sub>2</sub>=Subzone of *Productus Cora*, mut. S<sub>2</sub>. (The main portion of the *Seminula*-Zone.)

Lithological character.—Chiefly massive limestones, containing a thick series of oolites near the base, and concretionary limestones (with shale-partings) at the top.

Former designation.—The whole of the Middle Limestones, with the exception of the very topmost beds (which form the lower part of Zone D) and of the lowest beds (already described under subzone  $S_1$ ).

Where exposed in the Avon section:—

Clifton side:

- (1) The upper two-thirds of the Great Quarry, and the rocks at the side of the line up to the bottom of the new Zigzag Path.

NOTE.—All the beds above the base of the oolite (which occurs about the middle of the Great Quarry) are repeated by the Great Fault in St. Vincent's Rock.

- (2) In this repetition the higher portions of the *Seminula*-Zone are exposed, from the Great Fault (near the bottom of Bridge-Valley Road) almost up to the wall at the bottom of the old Zigzag Path.

Leigh Woods side:

- (1) Quarry 4, except the lowest beds; along the side of the line; Quarry 5 and the lower part of the series through which the tunnel is bored.
- (2) (Owing to the repetition by the Great Fault). Along the side of the river-path, from Nightingale Valley to the end of the riverside exposure.
- (3) Also in the disused quarry to the right of the road, immediately after crossing the Suspension-Bridge.

Coral-fauna:

*Alveolites septosa.*  
*Syringopora* cf. *distans*.  
*Lithostrotion Martini* & muts.

*Cyathophyllum Murchisoni.*  
*Clisiophyllum* (*Carcinophyl-*  
*lum*)  $\theta$ .

Brachiopod-fauna:

*Seminula ficoidea* and closely-  
allied forms.  
*Orthotetes crenistria*, mut. S.  
*Productus* aff. *hemisphericus*.

*Productus Cora*, mut.  $S_2$ .  
*Productus* 'giganteus'.  
*Chonetes papilionacea*.  
*Chonetes* aff. *comoides*.

A characteristic bryozoan in this subzone is *Chætetes* (?) *radians*.

Special faunal characters:—

*Lithostrotion Martini*, *Seminulae*, and *Producti* abound throughout. *Chonetes papilionacea* and *Syringopora* sp. are common at recurring levels.

*Clisiophyllids* occur sparingly from the base of the oolite onwards, and are chiefly represented by *Clisiophyllum*  $\theta$ .

*Orthotetes*, *Alveolites*, and *Cyathophyllum Murchisoni* are rare.

*Productus* 'giganteus' becomes abundant at the top of the subzone.

*Productus Cora*, mut.  $S_2$ , attains its maximum in the *Seminula*-oolite.

*Productus* aff. *hemisphericus* gradually increases in numbers.

D=Zone of *Dibunophyllum* aff. *turbinatum*  
(*DIBUNOPHYLLUM*-Zone).

Lithological character.—In ascending order:

- (1) Massive limestones.
- (2) Shales and grits.
- (3) Massive limestones.
- (4) Shales.

Former designation:

- (1) The upper part of the Middle Limestone.
- (2) The Upper Limestone-Shales (lower part).
- (3) The Upper Limestone in the Upper Limestone-Shales.
- (4) The Upper Limestone-Shales (upper part).

Where exposed in the Avon section:—

Clifton side:

On either side of the new Zigzag Path and, along the side of the railway-line, between the bottom of that path and the tunnel-entrance (near Point Villa).

In small exposures along the riverside path, from the entrance to the new Zigzag up to Point Villa, and in a continuous exposure from that point to the wall at the bottom of Bridge Valley-Road, also along the side of Bridge Valley-Road.

In the repetition of the series after the fault, this zone is met with just before the wall at the bottom of the old Zigzag Path; and, after passing the entrance to that path, it extends continuously up to the Rocks Railway. Beyond this point the beds are hidden by the Colonnade, and, farther on, by St. Vincent's Parade.

Leigh Woods side:

Near the point on that side and, after a considerable break, in Quarry 6 at the foot of Stokeleigh Camp and in the exposures on the side of the camp.

In the repetition of the series after the fault, the zone can again be studied in the Quarry on Rownham Hill.

Coral-fauna:

*Alveolites septosa* and varieties.  
*Syringopora* cf. *distans*.  
*Syringopora* cf. *geniculata*.  
*Lithostrotion Martini* and variants (especially towards *L. irregulare* and *Lonsdalia*).  
*Lithostrotion irregulare* and variants.  
*Lithostrotion junceum*.  
*Lithostrotion Portlocki* and variants (such as *L. M'Coyanum*, *L. ensifer*).

*Cyathophyllum Murchisoni* and variants.  
*Cyathophyllum regium*.  
*Campophyllum* aff. *Murchisoni*.  
*Clisiophyllids* of numerous types (such as *Clisiophyllum* θ and the group of *Dibunophyllum* aff. *turbinatum*).  
*Lonsdalia floriformis*.  
*Lonsdalia* aff. *rugosa*.  
*Azophyllum* θ.

## Brachiopod-fauna:

(?) *Dielasma hastata*,  
*Seminula ficoidea* and allied  
 forms.  
*Orthotetes crenistria*, mut. D.

*Productus* aff. *Cora*, mutations.  
*Productus giganteus*.  
*Productus hemisphericus* & vars.  
*Chonetes* aff. *comoides*.

## Subdivisions:—

$D_1$  = Subzone of *Dibunophyllum*  $\theta$  and *Dibunophyllum*  $\phi$   
 ( $\theta\phi$ -subzone).

Where exposed in the Avon section:—

## Clifton side:

Of the exposures already mentioned as included in the whole zone, those up to a little beyond Point Villa before the fault, and the whole of the exposure mentioned after the fault, belong to this subzone.

NOTE.—Fossils labelled 'Point,' 'Hotwell House,' 'Boiler-Bed,' and 'Behind the Colonnade,' etc. are derived from beds in this subzone.

## Leigh Woods side:

The beds near the Point on that side of the river.

## Special faunal characters:—

## Brachiopods:

*Productus* '*giganteus*'<sup>1</sup> abounds towards the base, and the thick-shelled *Chonetes* aff. *comoides* is not rare.

*Productus* aff. *Cora* occurs in a well-marked mutation.

*Pr. hemisphericus* is abundant just above the rich coral-band.

*Seminula ficoidea* is uncommon and *Orthotetes* rare.

## Corals:

*Cyathophyllum Murchisoni* teems in several well-marked varieties, between which there are complete transitions.

Clisiophyllids belonging to both the *Clisiophyllum*- and *Dibunophyllum*-sections reach their maximum, the most abundant forms being cylindrical or elongate members of the group of *Dibunophyllum* aff. *turbinatum*, which are here designated *D. \theta* and *D. \phi*.

*Syringopora* and *Alveolites* are both abundant (the commonest species of *Syringopora* being *S. cf. distans* and *S. cf. geniculata*).

*Campophyllum* aff. *Murchisoni* reaches its maximum.

A Koninckophyllid *Cyathophyllum* occurs rarely.

*Lithostrotion Martini* and its mutations are not uncommon, but are far less abundant than in the zone below.

*Lithostrotion irregulare* becomes important.

*Lithostrotion junceum* occurs, but is never abundant.

In the Avon section this subzone is chiefly recognized by the enormous abundance of simple *Cyathophylla* and of elongate *Dibunophylla*, both of which groups reach their maxima.

<sup>1</sup> *Productus* '*giganteus*' merely implies large, convex *Producti*, with close and flexuous, longitudinal ribbing and broad, over-rolled beak. It is a convenient field-term, but I am ignorant of the hinge-characters.

D<sub>2</sub> = Subzone of *Lonsdalia floriformis* (LONSDALIA-Subzone).

Where exposed in the Avon section:—

Clifton side:

- (1) In the riverside exposure, from a little above Point Villa to the end of the exposure (that is, to the wall at the bottom of Bridge Valley-Road).
- (2) At the side of Bridge Valley-Road.  
(The first-named exposure is known as 'Round Point').

Leigh Woods side:

In Quarry 6 and in the exposures on the side of Stokeleigh Camp.

In the quarry on Rownham Hill.

Special faunal characters:—

Brachiopods:

*Productus 'giganteus'* and *Pr. cf. latissimus* are not uncommon.

Spiriferids and Athyrids are very rare, and their identification awaits further material.

Corals:

*Cyathophyllum regium*, the group of *Lithostrotion* typified by *L. Portlocki* and *L. ensifer*, and *Lonsdalia floriformis* and its variants only occur in this subzone, where they are abundant and highly characteristic.

The Clisiophyllids are common, especially in the conical forms of the *Dibunophyllum* aff. *turbinatum*-group which are here designated *Dibunophyllum*  $\psi$ .

*Lithostrotion Martini* in its typical form is rare, but the mutations towards *L. irregulare* and towards *Lonsdalia* are very characteristic. *Lithostrotion irregulare* reaches its maximum. *Lithostrotion junceum* occurs sparingly.

*Axophyllum* is common.

*Alveolites* is fairly abundant, as is also one of the *Syringopora* (cf. *Syringopora distans*).

*Cyathophyllum Murchisoni*, although common, is not so prolific as in the lower subzone.

$\epsilon$  = Horizon  $\epsilon$ .

Lithology.—Shales and hard grits (somewhat calcareous).

Former designation.—Millstone-Grit (lower part).

Where exposed in the Avon section.—Now bricked up, but formerly exposed at the farther end of St. Vincent's Parade (behind the 'General Draper' public-house) on the Clifton side.

## Fauna:

*Productus* aff. *scabriculus* crowds the beds.

(The form common in the Avon section is better described as a scabriculate variety of *Pr. costatus*.)

*Orthotetes* and *Productus* aff. *Cora* are apparently not uncommon.

NOTE.—My whole knowledge of this horizon in the Avon section is derived from specimens preserved plentifully in local collections.

## Analysis of Stoddart's paper dealing with the Palæontological Sequence in the Avon Section.<sup>1</sup>

(Solely with reference to the Corals and Brachiopods.)

The fossils cited in that paper will, for convenience, be designated by different letters, according as they fall into one or other of the following classes:—

- A. Those represented in the collection under the name cited in the paper and so localized as to suggest the horizon at which they are recorded.  
(With one or two exceptions the horizon is stated very broadly; as, for example, Black Rock, Lower Limestone-Shales, Middle Limestone, etc.)
- C. Those unrepresented in the collection (at least so far as the particular bed under consideration is concerned).

The class C will be subdivided into:—

- C 1. Those which may be accepted as really occurring at the horizon stated.

(Here I include those fossils which are usually identified correctly in the collection, or could not easily be mistaken for any of the other fossils known to occur at the particular horizon.)

- C 2. Those which should be rejected as erroneous determinations.

(Here I include all fossils which are habitually determined erroneously in the collection.)

The fossils are grouped into the zones that I have suggested; the number in front of the name is that employed by Stoddart to denote the particular bed in which the fossil occurs; the letter after the name has the meaning explained above; and I append the name under which the fossil is recorded in my own work.

In some cases, the alteration in name consists merely in the employment of more recent generic nomenclature; in others it consists in more accurate specific identification; while in several, Stoddart's determination undoubtedly was entirely erroneous.

The names given in inverted commas are those cited by Stoddart, and they are here considered to denote the fossils so named by him in the Stoddart Collection: as, for example, '*Rhynchonella pleurodon*,' in the sense implied by Stoddart (that is, *Pugnax pugnax*), is not known to occur in the *Modiola*-Zone; whereas the common *Rhynchonella* in this zone is called '*Retzia radialis*' by Stoddart, and would probably have been passed by Davidson as a variety of *Rhynchonella pleurodon*.

**MODIOLA-ZONE.** (Beds 1 to 5.)

(2 & 4) '*Athyris Royssii*'; A; *Cliothyris Royssii*.

(2) '*Spirifera rhomboidea*'; C 2; probably indicates a *Spirifer* of considerable transversity.

(2) '*Retzia radialis*'; A; *Rhynchonella mitcheldeanensis*.

<sup>1</sup> Proc. Bristol Nat. Soc. n. s. vol. i (1875) pp. 318 *et seqq.*



- (4) '*Rhynchonella pleurodon*'; C 2; (specimens labelled '*Rh. pleurodon*' are certainly not from this zone).  
 (4) '*Lingula* and *Discina*'; C 1.  
 (4) '*Chonetes hardrensis*'; C 1.  
 (4) '*Streptorhynchus crenistria*'; C 1; *Orthotetes crenistria*.  
 (4) '*Spirifer bisulcatus*'; C 2; merely denotes a *Spirifer* of no great transversity.  
 (4) '*Terebratula hastata*'; C 2; possibly *Cliothyris Royssii*.

Horizon  $\alpha$ . (Bed 6.)

- (6) (The 'Bryozoa-Bed') '*Producta* sp.'; A; *Leptena analoga*.

CLEISTOPORA-ZONE. (Beds 8 to 12 and possibly 13; the position of Bed 13 is doubtful, as the fossils recorded are not obtained from the actual Avon section; it may occur either just below or even above Bed 14, or it may be the equivalent of that bed.)

- (7) (The 'Palate-Bed') '*Discina* and *Lingula*'; A.  
 (8) '*Camarophoria globulina*'; C 2; possibly *Rhynchonella* aff. *mitchelleanensis* (that is, the small globular form in which the pleats are few and coarse, and are indistinct near the beak).  
 (8) '*Athyris Royssii*'; C 1; *Cliothyris Royssii* or a mutation.  
 (8) '*Athyris lamellosa*'; C 2; probably a transverse variety of *Cliothyris Royssii*.  
 (8) '*Retzia radialis*'; A; *Rhynchonella mitchelleanensis*.  
 (8 & 13) '*Spirifer duplicicosta*'; A; *Spirifer* aff. *clathratus*.  
 (9) '*Chonetes Buchiana*'; A; *Chonetes* cf. *Buchiana*.  
 (9 & 12) '*Chonetes sordida*,' 'var. *perlata*,' 'papilionacea'; A; *Chonetes* cf. *hardrensis*.  
 (9, 11, & 13) '*Orthis resupinata*'; A; *Rhipidomella* aff. *Michelini* & *Productus* sp.  
 (9, 11, & 13) '*Streptorhynchus crenistria*,' 'var. *arachnoidea*'; A; *Orthotetes crenistria* (var.). The var. '*arachnoidea*' is merely the flatter valve.  
 (10) '*Rhynchonella pleurodon*'; C 2; a specimen of *Pugnax pugnax* is so labelled, but is insufficiently localized.  
 (13) '*Terebratula hastata*,' 'var. *ficus*,' 'var. *sacculus*,' 'var. *vesicularis*'; A; *Cliothyris Royssii* (mut.).  
 (13) '*Rhynchonella acuminata*'; A (?); *Pugnax acuminata* (a specimen is labelled 'Lr. Carb.').<sup>1</sup>  
 (13) '*Spirifer mosquensis*'; A; *Spirifer* cf. *bisulcatus*, an axially-elongate variety.  
 (13) '*Spirifera glabra*'; A; ? *Martinia glabra*, var. *linguifera* (or *Spiriferina rostrata* from the Lias).  
 (13) '*Strophomena analoga*'; A; *Leptena analoga*.

Horizon  $\beta$ . (Bed 14, and probably Bed 13.)

- (14) '*Spirifera striata*' and var. '*attenuata*'; A; *Spirifer* aff. *clathratus* and its variety.  
 (14) '*Spirifera cuspidata*'; A; *Syringothyris* aff. *cuspidata*.  
 (14) '*Producta punctata*'; C 2.  
 (14) '*Producta pustulosa*'; C 2; probably the interior of the concave valve of *Productus* aff. *semireticulatus*, which is not uncommon.

But a *Productus* with discontinuous ribbing does occur at this horizon in the Bristol area.

- (14) '*Athyris Royssii*'; ?; *Cliothyris Royssii* (mut.).

<sup>1</sup> I do not know *Pugnax* below D; the specimen in the Stoddart Collection was derived from a matrix with which I am unacquainted in the Tournaisian of the Bristol area.

ZAPHRENTIS-ZONE and Horizon  $\gamma$ .

Although there are numerous specimens in the collection from these beds, the only bed cited is the 'Fish-Bed' (15).

## SYRINGOTHYRIS-ZONE.

No fossils are cited from the main portion of this zone.

## SEMINULA-ZONE.

S<sub>1</sub> SUBZONE. (Beds 16 to 19, and probably Beds 20 & 21.)

- (16) '*Terebratula hastata*'; A; *Seminula ficoidea*.
- (17) '*Lithostrotion Aranea*'; A; *Lithostrotion basaltiforme* (var.).
- (17) '*Lithostrotion irregulare*'; A; *Lithostrotion Martini* (small var.).
- (17 & 18) '*Lithostrotion junceum*'; C 2; probably *Syringopora* sp., which is common at this level, but not cited.
- (17) '*Producta punctata*'; ?; a specimen of *Pr. elegans* is represented in the collection, but not horizoned.
- (18) '*Producta longispinosa*'; A; *Productus semireticulatus* (mut. S<sub>1</sub>).
- (19) '*Producta Martini*'; ?; *Productus* aff. *semireticulatus*.
- (19) '*Producta Cora*'; A; *Productus*  $\theta$ .
- (19) '*Rhynchonella acuminata*'; ?; I feel doubtful that the specimen in the collection is local.
- (20) '*Lithostrotion Portlocki*'; C 3; probably a small form of *L. basaltiforme* (var.).
- (20) '*Cyathophyllum regium*'; C 2; } one or other name must
- (20) '*Cyathophyllum turbinatum*'; C 2; } denote the abundant *Caninia cylindrica* var. *bristolensis*, which is well represented in the collection.
- (20) '*Michelinia tenuisepta*'; A (?); can only be regarded as probable evidence of *Michelinia*.
- (21) '*Cyrtina septosa*'; C 2; may denote *Syringothyris* aff. *laminosa*.
- (21) '*Spirifera lineata*'; C 2.

S<sub>2</sub> SUBZONE. (Beds 40 & 41.)

- (40) '*Terebratula hastata*'; A; *Seminula ficoidea*.
- (40) '*Syringopora geniculata*'; ?
- (41) '*Producta*'; A.
- (41) '*Rhynchonella pugnus*'; C.

## DIBUNOPHYLLUM-ZONE.

$\theta\phi$ -SUBZONE. (Beds 23 to 29 and Beds 42 to 45.)

- (23) '*Aulophyllum fungites*'; C; } probably denote the *Clisiophyl-*
- (23) '*Clisiophyllum coniseptum*'; C; } lids which are represented in the collection.

But *Cycliphyllum* does occur at this horizon, although very rarely.

- (23) '*Lithostrotion concinnum*'; C; probably *Lithostrotion Martini* (mut.).
- (23) '*Cyathophyllum regium*'; C; most probably *Cyathophyllum Murchisoni*, which seems at this horizon and is well represented in the collection.
- (25) '*Terebratula vesicularis*'; C; probably *Seminula* sp.
- (26 & 42) '*Chaetetes radians*'; A; *Chaetetes bristolensis*.
- (26) '*Lithostrotion irregulare*'; ?
- (27) '*Chonetes comoides*'; C 1; probably *Ch.* aff. *comoides*.
- (27) '*Producta Cora*'; A; *Productus* aff. *Cora*, mut. S<sub>2</sub>.
- (27 & 42) '*Alveolites septosa*'; A.
- (28) '*Zaphrentis Griffithsi*'; C 2.
- (28) '*Amplexus coralloides*'; C 2; (probably named from a vertical section of *Campophyllum* aff. *Murchisoni*, which is common at this horizon).
- (29 & 42) '*Producta gigantea*'; C 1.
- (42) '*Syringopora reticulata*, *S. geniculata*, and *S. lamellosa*' (? *ramulosa*); A; *Syringopora* spp. (awaiting accurate separation).

- (42) '*Lithostrotion junceum*'; ?  
 (42) '*Lithostrotion affine*'; A; *Lithostrotion Martini* (mut.).  
 (44) '*Rhynchonella pugnus*'; C.

*LONSDALIA*-SUBZONE. (Beds 31 to 35 and Beds 46 & 47.)

- (31 & 34) '*Lithostrotion irregulare*'; A; *Lithostrotion irregulare* and *L. Martini* (mut. towards *L. irregulare*).  
 (33, 35, & 47) '*Cyathophyllum regium*'; A.  
 (35 & 47) '*Cyathophyllum Stutchburyi* and *C. Murchisoni*'; A; *Cyathophyllum Murchisoni*.  
 (33) '*Lithostrotion ensifer*'; A.  
 (33 & 47) '*Lithostrotion Martini*'; A.  
 (33) '*Lithostrotion basaltiforme*'; C 2; } probably *Lithostrotion*  
 (47) '*Lithostrotion carnea*' (? *Aranea*); C 2; } *Portlocki*, which seems  
 at this horizon and is well represented  
 in the collection, but not cited in the  
 paper.  
 (47) '*Lithostrotion M'Coyanum*'; ?  
 (33) '*Lithostrotion junceum*'; ?  
 (33 & 47) '*Lonsdalia floriformis*'; A.  
 (33) '*Aulophyllum fungites*'; C; } probably denote members of  
 (33) '*Clisiophyllum coniseptum*'; C; } the *Dibunophyllum-turbinatum*  
 group.  
 (33) '*Alveolites depressa*'; A; *Alveolites septosa*, var.  
 (47) '*Campophyllum Murchisoni*'; C 1; (no specimens are so labelled;  
 the ones that I have noticed are from  
 Bed 44).

Horizon  $\epsilon$ .

- (48) '*Spirifera rhomboidalis*' or '*convoluta*'; C 2.  
 (48) '*Cyrtina septosa*'; C 2.  
 (48) '*Producta Martini*'; C 2; } probably *Productus* aff. *scabri-*  
 (48) '*Producta longispinosa*'; C 2; } *culus*.

The following corrections of my own observations seem to be the only ones that can be reliably deduced from Stoddart's paper, and from the fossils in his collection which are adequately horizoned:—

I. The following brachiopods probably occur in the *Modiola*-Zone below Horizon  $\alpha$ :—

- (4) *Lingula* sp.; (*Discina*) sp.; *Orthotetes crenistria*; *Chonetes* cf. *hardrensis*; (2 & 4) *Spirifer* sp. or *Syringothyris* sp.

II. *Productus bassus* may extend nearly up to Horizon  $\beta$ .

(A specimen in the collection is labelled 'Below the Black Rock.')

III. *Michelinia* possibly extends up into the *Seminula*-Zone ( $S_1$  subzone).

(b) Introduction to the Sodbury Carboniferous Limestone.

Chipping Sodbury lies about 11 miles in a direct line east 30° north of the Clifton Suspension-Bridge.<sup>1</sup>

The exposures from which the following account has been derived are:—

- (1) The railway-cutting on the new South-Wales Direct Line.
- (2) The two large town-quarries at the west of the town, north of the Bristol road.

<sup>1</sup> The Suspension-Bridge is chosen as the point from which all distances in this account of the Bristol area are measured, because it spans part of the Avon section. The rocks upon which it rests belong to the upper part of the *Seminula*-Zone, in the repetition of that zone caused by the Great Fault.

The railway lies nearly half a mile south of the town; it cuts 2500 feet (measured horizontally) of Carboniferous-Limestone rocks which dip almost due westward at an average angle of 44°. The cutting exhibits a complete sequence, from the top of the Old Red Sandstone up to the lowest part of the *θφ*-subzone, but ends before the *Lonsdalia*-Subzone is reached.

In a new cutting, made through hard rocks entirely by blasting, the utmost care has to be exercised that all the fossils recorded have been found absolutely *in situ*. Loose material must be entirely disregarded, since it may have been brought from any distance, dropped from the trucks, and have reached its final position as the result of subsequent blasting-operations. On the other hand, the loose material in a quarry may, with more safety, be assumed to have been derived from the beds exposed in the quarry.

It is also to be remembered that, since a fresh cutting shows no weathered surfaces, any fossils, but especially corals, are apt to escape notice which, in the disused part of a quarry, immediately arrest the attention.

For these reasons the failure to record any particular species in the Sodbury cutting cannot be considered to prove more than its non-abundance. For example, no *Clisiophyllid* was recorded in the cutting from the whole of the *Seminula*-Zone, whereas several specimens from this zone were detected in the first quarry.

## SODBURY.

### Tournaisian.

#### *Modiola*-Zone (M).

Lithological character.—Shales, grits, and calcareous bands ending with a series of red limestones (Horizon *a*).

Exposure.—The upper portion of the small Palæozoic projection which is separated from the main Carboniferous Limestone elevation by a broad valley, deeply filled in with the Lower Jurassic strata.

#### Fauna:—

##### (1) From the beds below Horizon *a*.

An ostracod is not uncommon (this is apparently the same as the common Avon species).

Fragments of a lamellibranch (possibly *Modiola*).

##### (2) From Horizon *a*.

*Rhabdomeson* and fragments of crinoids are very abundant.

*Cliothyris Royssii*.

Correlation with the Avon section.—The few fossils recorded above are all abundant at the same levels in the Avon section.

#### *Cleistopora*-Zone (K).

Lithological character.—A well-marked 'Palate-Bed' at the base, followed by a thick series of shales with subsidiary limestones.

**Exposure.**—The greater part of this zone lies at, or beneath, the level of the roadway, so that it can only be examined in the occasional bands of harder limestone or in the drainage-trenches at the foot of the slopes. The basal beds of the zone can, however, be more easily worked, since they form the western extremity of the small Palæozoic projection already mentioned.

The zone may be considered to end at the base of the massive Limestone-series which commences at Kingrove-Farm Bridge.<sup>1</sup>

**Fauna.**—The 'Palate-Bed' is crowded with coprolites, and palatal teeth are abundant in it; similar teeth are found less frequently in the overlying beds, for a considerable distance.

**Corals:** none found.

**Brachiopods:**

(1) *bassus*-subzone ( $K_1$ ).

<i>Eumetria</i> (' <i>Retzia</i> ') aff. <i>carbonaria</i> . <i>Camarotoechia mitcheldeanensis</i> . <i>Leptena analoga</i> . <i>Orthotetes crenistria</i> , especially mut. $K_1$ . <i>Syringothyris</i> aff. <i>cuspidata</i> . <i>Spirifer</i> aff. <i>clathratus</i> . <i>Cliothyris Royssii</i> . <i>Chonetes</i> cf. <i>hardrensis</i> .	} All extremely abundant.
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(2) *octoplicata*-subzone ( $K_2$ ).

*Spirifer* aff. *clathratus* and its variety become common in the very poor exposures near the top of the zone.

**Correlation with the Avon section.**—All the above fossils occur at the same levels in the Avon section. No specimen of *Cleistopora*, *Spiriferina octoplicata*, or *Productus bassus* has as yet been discovered at Sodbury. The failure to find the two first-named fossils is not a matter of surprise: (1) because of the practical absence of exposures in the upper part of the zone; and (2) on account of the difficulty of noticing either fossil except on weathered surfaces, which are necessarily rare in a new cutting.

$K_1$ .—Though *Productus bassus* itself has not yet been met with at Sodbury, the subzone is well characterized by the great abundance of *Camarotoechia mitcheldeanensis*, *Leptena*, *Orthotetes*, and *Eumetria*; moreover, the particular forms of *Syringothyris cuspidata* and *Orthotetes crenistria* which occur in these basal beds are precisely those that are found at the same level in the Avon section.

$K_2$ .—This subzone may be said to be practically unexposed in the Sodbury cutting, but the increasing abundance of *Spirifer* aff. *clathratus* has been made out in its upper portion.

<sup>1</sup> This bridge crosses the railway-line, about 300 yards north of Kingrove Farm.

*Zaphrentis*-Zone (Z).

Lithological character.—Massive limestones, usually very ennerinital.

Exposure.—Massive limestones crowded with brachiopods, extending some 450 feet westward from Kingrove-Farm Bridge.

Fauna:—

Corals:

*Zaphrentis* aff. *Phillipsi*.

| *Syringopora* sp.

Brachiopods:

*Cliothyris Roysii* (mut.).

*Cliothyris glabristria*.

*Spirifer* aff. *clathratus* and variety.

*Reticularia* aff. *lineata*.

*Syringothyris* aff. *cuspidata*.

*Leptena analoga*.

| *Orthotetes crenistria* (mut. Z).

*Schizophoria resupinata*.

*Productus* cf. *Martini*.

*Chonetes* cf. *hardrensis*.

*Chonetes papilionacea*.

Subdivisions:—

(1) Horizon  $\beta$ .

Since *Zaphrentis* has not been found below the *resupinata*-subzone, and no specimen of *Spiriferina octoplicata* has been met with in the section, this horizon at Sodbury has no characters other than those common to the whole *clathratus*-subzone, of which it forms the base.

(2) *CLATHRATUS*-subzone ( $Z_1$ ).

This subzone is well characterized by the extreme abundance of *Spirifer* aff. *clathratus* and its variety.

*Orthotetes crenistria*, in the mutation characteristic of the *Zaphrentis*-Zone, is abundant.

*Leptena analoga* and *Chonetes* cf. *hardrensis* are common.

*Cliothyris glabristria*, *Reticularia* aff. *lineata*, *Cliothyris Roysii* (mut.), and a *Syringopora* are not infrequent.

*Productus* cf. *Martini* is only recorded doubtfully.

(3) *RESUPINATA*-subzone ( $Z_2$ ).

This subzone is well defined by the abundance of *Cliothyris glabristria* and *Schizophoria resupinata*, as well as by the fact that in it *Zaphrentis* attains its maximum.

*Chonetes* cf. *hardrensis* crowds the beds at the bottom of the subzone, while, at the top, *Chonetes papilionacea* is the predominant form and is equally prolific.

*Syringothyris* aff. *cuspidata* occurs abundantly in the lower half of the subzone, and that mutation of *Orthotetes* which is characteristic of the *Zaphrentis*-Zone is common throughout.

*Leptena* and *Productus* cf. *Martini* (large form aff. *Pr. semireticulatus*) are met with not infrequently.

*Syringopora*  $\theta$  has been noted at two levels.

(4) Horizon  $\gamma$ .

This horizon is not defined with precision, since no specimen of *Caninia* has been found in association with *Zaphrentis*;

it may, however, be fixed within very narrow limits, as embracing that portion of the zone in which *Zaphrentis* is still common, but *Cliothyris glabristria* becomes scarce; the band of *Chonetes papilionacea* may thus be taken as occurring at the base.

Correlation with the Avon section:—

(1) Resemblances:

In both sections:—The maximum of *Spirifer* aff. *clathratus* is followed by that of *Cliothyris glabristria*, while *Zaphrentis* attains its maximum when *Cl. glabristria* becomes scarce.

*Schizophoria* is abundant, and confined to the *resupinata*-subzone.

*Chonetes* cf. *hardrensis* is predominant in the lower part of the Zone, but yields place to *Chonetes papilionacea* at the top.

The same mutation of *Orthotetes* abounds throughout, and the same species of *Syringopora* is found.

(2) Differences:

No specimen of *Zaphrentis* has been found at Sodbury before the upper part of the *resupinata*-subzone, and no *Caninia*, *Amplexus*, or *Michelinia* has been discovered in any part of the *Zaphrentis*-Zone (though specially looked for).

The presence of *Zaphrentis* in the lower part of the zone and of *Amplexus* and *Michelinia* at the top might, perhaps, have escaped notice, even if they occur in the same numbers as in the Avon section; but the failure to find a single *Caninia* at the top of the zone seems to point definitely to the conclusion that the incoming of this genus suffered a great retardation towards the north-east.

(A point of some interest is the fact that in both the Avon and Sodbury sections there is, in this zone, a thick series of relatively-unfossiliferous beds which are characteristically interlaced with veins and patches of calcite; this series occurs at the top of the *clathratus*-subzone at Sodbury, but is found in the middle of that subzone in the Avon section.)

### *Caninia*-Zone.

This zone includes:—

C = The *Syringothyris*-Zone at the top of the Tournaisian;  
and S<sub>1</sub> = The *semireticulatus*-subzone at the base of the Viséan.

These two subzones are conveniently considered together in this place, in order to emphasize the palæontological break between the Tournaisian and the Viséan in the northern part of the Bristol area, where that break is most evident.

Lithological character:—

- |                  |   |
|------------------|---|
|                  | (1) At the base relatively-unfossiliferous, massive, encrinital limestones.                           |
| C {              | (2) A band of oolitic limestone (unfossiliferous except for occasional fragments of crinoids).        |
|                  | (3) A series of shales, including thick beds of dolomite and an occasional bed of oolite; ending in a |
| S <sub>1</sub> { | prominent band of pure quartzose grit.  |
|                  | (4) Massive fossiliferous limestones.   |

Exposure.—The middle part of that portion of the section which lies between Kingrove-Farm Bridge and Lilliput-Farm Bridge.

Faunal character:—

Top of the Tournaisian: C.

*Zaphrentis* is not uncommon in the lower part of (1).

*Chonetes* aff. *papilionacea* and *Orthotetes crenistria*, associated together, crowd certain bands near the top of (1), and the last-mentioned fossil passes on into the base of (2).

*Syringothyris* aff. *laminosa* occurs in considerable numbers, just below (2).

Base of the Viséan: S<sub>1</sub>.

{ *Seminula ficoidea* and its variants enter about the middle of (3), and from that point become increasingly abundant.  
*Productus*  $\theta$  (?)<sup>1</sup> occurs sparingly in (3).

Both these fossils teem throughout (4).

*Caninia cylindrica* (var. *bristolensis*) and *Lithostrotion Martini* enter together at the top of (4), and are there extremely abundant.

*Syringopora* cf. *distans* is common in the upper part of (4).

The zone is considered to end where *Caninia* dies out.

Correlation with the Avon section:—

Resemblances:

All the fossils which occur at Sodbury enter in precisely the same relative order as they do in the Avon section.

In both sections:—After *Zaphrentis* has died out *Syringothyris* aff. *laminosa* becomes an important distinctive fossil, and certain beds are crowded with *Orthotetes* and *Chonetes* aff. *papilionacea*.

*Orthotetes* ends its long predominance at the same level and, throughout the rest of the Carboniferous Limestone, plays an extremely-minor part.

*Seminula* becomes abundant, before giganteid *Producti* and *Lithostrotion Martini* are met with in any numbers.

At the top of the zone *Caninia cylindrica* var. *bristolensis* is as abundant at Sodbury as in the Avon section, and is similarly associated with crowds of *Lithostrotion Martini*, *Productus*  $\theta$  (?), and *Seminula*, as well as with the same species of *Syringopora*.

Differences:

Owing to the absence (or scarcity) of *Caninia* at the base of the zone, the lower part of the *Caninia*-Zone (*Syringothyris*-Zone) appears to be entirely distinct from the upper part (*semireticulatus*-subzone). In fact, at Sodbury, the palæontological facies of the Lower Carboniferous Limestone (which comprises the zones of *Clestopora*, *Zaphrentis*, and *Syringothyris*) is so entirely distinct from that of the *Seminula*-Zone above, that it would seem impossible to include the whole series in one system.

The only genera which bridge the gap at Sodbury are *Syringopora*, *Productus*, and *Orthotetes*. The species of *Syringopora* that

<sup>1</sup> A field-determination, and possibly including *Productus* aff. *hemisphericus*.



occur above are certainly not identical with those that are found below.

*Orthotetes*, which is enormously prolific throughout the lower portion of the Carboniferous Limestone, becomes extremely rare (and distinct in form) in the upper.

The *Producti* of the upper portion belong to the giganteid group, of which group no representatives have been found in the lower part at Sodbury.

This sharp distinction of a lower system (Tournaisian) from an upper (Viséan) is at Sodbury a definite fact which cannot be overlooked. It is only by the study of the whole series in other parts of the Bristol area, where the transition becomes more gradual, that the complete distinction of an upper and a lower system is seen to break down. At Sodbury the occurrence of *Caninia* is an isolated phenomenon of the Lower Viséan; farther south and west, this genus is seen to be the result of direct evolution from *Zaphrentis* in the Upper Tournaisian.

[The general resemblance of the lithological character of this zone in the two sections is striking:—

The poorly-fossiliferous encrinital limestones at the base (top of the Lower Limestone), the band of oolite (equivalent to the Gully Oolite), the shales and dolomites (equivalent to the Middle Shales), and the massive limestone at the top (equivalent to the bottom of the Middle Limestone) are represented in the same order in the two sections, and the beds have similar textures.

The differences are of less importance, and consist (1) in an inflation of the dolomite-bands at Sodbury: therefore, in that section, the Middle Shales would be more aptly termed 'the Middle Dolomites'; and (2) in the occurrence of the highly-quartzose grit-band.]

### Viséan.

*Seminula*-Zone (including  $S_1$  and  $S_2$ ).

$S_1$  has already been discussed under the *Caninia*-Zone, but is again included here for the reasons already given.

Lithological character:—

- |       |   |
|-------|---|
| $S_1$ | { Shales, dolomites, and grits.   |
| $S_2$ | { A long series of massive limestones, containing thick oolitic beds, are succeeded by a thick series of concretionary beds ('mottled limestones') with shale-partings. The mottled limestones exhibit the peculiar character of Cotham Marble, and have a very similar concretionary surface; Mr. A. Strahan <sup>1</sup> has pointed out their similarity to the Mumbles-Head Beds. |
|       | { The uppermost part of the zone is composed of thick shales with several bands of grit.  |

<sup>1</sup> Mem. Geol. Surv. 'Summary of Progress Report for 1902' p. 193.

## Exposures:—

- $S_1$  &  $S_2$  { (1) In the cutting on both sides of Lilliput-Farm Bridge.  
 $S_2$  { (2) In the two quarries at the western end of the town, north of the Bristol Road.

The first, or easternmost, of the two quarries exhibits the massive limestones, with a thick oolite-band at the top.

The second affords a splendid section of the mottled-limestone series and of the shales and grits above.

## Faunal character:—

## Corals:

*Syringopora* cf. *distans*.

*Lithostrotion Martini* & variants.

*Cyathophyllum Murchisoni* (?).<sup>1</sup>

*Clisiophyllum*  $\theta$ .

## Brachiopods:

*Seminula ficoidea* and its allies.

*Productus*  $\theta$  (?).

*Productus* aff. *Cora*.

*Productus* 'giganteus'.

*Chonetes papilionacea*.

## Notes:—

*Caninia* occurs only at the top of  $S_1$ , as already stated.

*Lithostrotion Martini* starts at the top of  $S_1$ , reaches its maximum a little above the very top of that horizon, and greatly diminishes in numbers afterwards.

*Syringopora* cf. *distans* is not uncommon throughout the same range.

*Clisiophyllum*  $\theta$  occurs in some numbers in the main oolite-band.

*Cyathophyllum Murchisoni* (?) occurs rarely in the concretionary series, and in some of the limestone-bands included in the thick shales.

*Seminula ficoidea* starts at the very base of  $S_1$  (that is, in the middle of the dolomites) and remains extremely abundant right up to the top of the shales.

*Productus*  $\theta$  (?) occurs in  $S_1$  (the specific determination is doubtful). *Productus* aff. *Cora* (mut.) is common in  $S_2$ , up to the concretionary beds. *Productus* 'giganteus' attains a maximum just below the concretionary beds, and is also common in them.

*Chonetes papilionacea* teems at two or three levels between the top of  $S_1$  and the bottom of the concretionary beds.

Correlation with the Avon section.—The similarity of faunal distribution amounts almost to identity; the only difference seems to be the retardation at Sodbury of the entrance of *Lithostrotion*, which, there, first appears at the maximum of *Caninia*, whereas in the Avon section it enters a few beds below.

In lithological character, the chief point of difference is the great inflation at Sodbury of the concretionary limestones and of the shales above them.

<sup>1</sup> This is a field-determination.

*Dibunophyllum*-Zone. $\theta\phi$ -subzone ( $D_1$ ).

Lithological character.—Massive limestones, to a large extent oolitic, containing a band of quartz-conglomerate with 'veinstone-quartz' pebbles.

## Exposures:—

(1) The end of the Carboniferous-Limestone exposure in the cutting.

(2) The uppermost beds of the second quarry.

NOTE.—Only the lowest part of the subzone  $\theta\phi$  is exposed at Sodbury; the higher part of that subzone and the whole of the *Lonsdalia*-Subzone are entirely unexposed.

## Faunal character:—

## Corals:

*Alveolites septosa.*

*Syringopora* cf. *distans*.

*Lithostrotion Martini* (mutations towards *L. affine*).

*Lithostrotion irregulare.*

*Cyathophyllum Murchisoni* and variants.

Clisiophyllids, including *Clisiophyllum*  $\theta$ , *Dibunophyllum*  $\theta$  and  $\phi$ , *Koninckophyllum*  $\theta$ .

## Brachiopods:

*Productus 'giganteus.'*

*Productus hemisphericus* & vars.

*Chonetes* aff. *comoides*.

*Orthotetes crenistria* (mut. D).

*Seminula ficoidea.*

*Athyris* cf. *expansa*.

Correlation with the Avon section.—The two sections are palæontologically identical, the same fossils occur in each and in the same relative abundance.

*Campophyllum* aff. *Murchisoni* which, in the Avon section, attains its maximum near the top of the  $\theta\phi$ -subzone has, however, not been found at Sodbury.

## (c) THE FAILAND AREA (including Flax Bourton).

Failand Inn lies 3 miles west  $22^\circ$  south of the Clifton Suspension-Bridge; it may be taken as the centre of the area. Just 1200 yards west of the Inn, measured along the Clevedon road, is a branch-road running northward to Portbury. After following this branch-road for 500 yards, exposures in the Carboniferous-Limestone Series begin to occur, and successively-lower beds are here and there exposed until, near Millpond Farm (some 1200 yards from the commencement of the road), the uppermost beds of the Old Red Sandstone are reached. This somewhat-discontinuous section includes almost the whole of the Tournaisian division of the Carboniferous Limestone, and will be referred to in this paper as the Failand section.

Turning back at Millpond Farm, we will retrace our steps towards the Clevedon road, so as to examine the beds in ascending order.

The lowest beds in the section have to be made out from the low roadside-cuttings, in which the rocks are only partly and occasionally exposed; this portion of the section (some 350 yards

horizontally) includes the *Modiola*-Zone (with Horizon  $\alpha$  well marked) and the greater part of the *Cleistopora*-Zone (only the lowest portion of this zone being at the time of my visits at all satisfactorily exposed).

Still proceeding southward, it was found that the sides of the road had, for the next 150 yards, been recently cut back, in such a manner as to afford a good section through Horizon  $\beta$  and the lower portion of the *Zaphrentis*-Zone.

A short distance farther south is a quarry in work (the 'Horse-Race' Quarry), which contains beds belonging to the upper part of the *Zaphrentis*-Zone. For the next 200 yards there are no exposures that can be easily examined; but, at the end of this distance, there are large quarries in the thick oolite-band which forms the middle portion of the *Caninia*-Zone. The remaining 500 yards of the road, to its junction with the Clevedon road, is destitute of exposures.

The thick band of oolite which forms the top part of the Failand section is the equivalent of the Gully Oolite in the Avon section, and, on account of its peculiar value for the manufacture of lime, this oolite is quarried at several points of the Failand area; it consequently serves as a very valuable horizon, from which to estimate the stratigraphical position of neighbouring exposures.

Before, however, an isolated quarry in this oolite can be used as a datum-level, it is imperative that the oolite in the quarry should be definitely proved to be the oolite from the *Caninia*-Zone, and not the thick oolite-band which, throughout the Bristol area, forms the middle part of the *Seminula*-Zone.

The following diagnostic characters completely distinguish these two oolitic bands:—

(i) The *Caninia*-Oolite.

At the base, *Orthotetes* (in association with *Chonetes papilionacea*) is extremely abundant, and *Syringothyris* aff. *laminosa* is common.

In the main part of the oolite fossils are uncommon, but *Seminula*, *Lithostrotion*, and *Productus* aff. *Cora* are never found.

(ii) The *Seminula*-Oolite.

This oolite is usually prolific in fossils, and *Seminula*, *Lithostrotion*, and *Productus* aff. *Cora* can always be found.

*Chonetes papilionacea* is, at the base of this oolite, quite as abundant as it is beneath the *Caninia*-Oolite; but *Orthotetes* is extremely rare.

Above the oolite of the *Caninia*-Zone occur the 'Bellerophon-Beds' (Horizon  $\delta$ ), the most interesting palæontological horizon in the Failand area. These beds are well shown in two isolated quarries only; the stratigraphical position of these quarries can, however, be very accurately fixed by means of the *Caninia*-Oolite which is worked near each of them.

The first of these 'Bellerophon'-quarries lies just behind Failand Inn, and about 100 yards south of the Clevedon road; its position is fixed by a shallow quarry, 350 yards west of Failand Inn, on the south side of the Clevedon road. The shallow quarry contains the lowest beds of an oolitic band, which is proved to belong to the

*Caninia*-Zone by the abundance of *Orthotetes* (in association with *Chonetes* aff. *papilionacea*) and the occurrence of *Syringothyris* aff. *laminosa*, at its base.

The strike in the '*Bellerophon*'-quarry and in the neighbouring *Caninia*-Oolite quarry is almost due east and west, while the dip in the former reaches  $27^{\circ}$ ; by plotting these data on the 6-inch map the '*Bellerophon*-Beds' are found to lie about 150 feet normally above the base of the oolite.

The second '*Bellerophon*'-quarry lies about 1000 yards west, very slightly south of the Failand-Inn quarry, in a direct line which almost exactly coincides with the strike at either quarry; the height of each quarry above sea-level is the same (450 feet).

Hence the identity of the two beds in the two quarries, which is sufficiently clear from palæontological considerations, is confirmed stratigraphically, and the determination of the position of the beds in the one quarry fixes that of the beds in the other. It is, however, easy to fix the position of the second quarry by independent evidence.

Wraxall Piece is a wooded patch bounded on the south-west by the Clevedon road; on the west by a branch-road to Failand Farm; on the north by a grass-grown road running east and west; and on the south-east by the road to Clifton, which branches off from the main Clevedon road at a point about 1250 yards east of Failand Inn. The second '*Bellerophon*'-quarry lies on the west side of the branch-road to Failand Farm, about 120 yards from its commencement in the Clevedon road.

Some 375 yards along this branch-road, opposite the western end of the grass-grown road, is a small disused quarry in which *Chonetes* aff. *papilionacea*, *Chonetes* cf. *hardrensis*, *Orthotetes*, and *Spirifer* were found *in situ*, while *Zaphrentis* sp. (cf. *Caninia*) was picked up among the loose material. Hence, the beds in this exposure may be, most probably, regarded as not higher than Horizon  $\gamma$ .

About 100 yards from this point, along the grass-grown road north of the Piece, is a small quarry in the lowest beds of the oolite, which is proved to belong to the *Caninia*-Zone by the abundance of *Orthotetes* (in association with *Chonetes* aff. *papilionacea*) at its base.

In the north-eastern corner of the Piece, by the side of the Clifton road, there is a large quarry in this oolite, but the lowest beds are very badly exposed, and the fossils are few and fragmentary, though *Orthotetes* was recognized. There can be no doubt that this is the same *Caninia*-Oolite, and that the beds here are a little higher than those in the quarry just described.

The strike both in the second '*Bellerophon*'-quarry and in the small oolite-quarry north of the Piece is almost due east and west, and the dip is nearly  $20^{\circ}$ . Plotting these data on the map, the '*Bellerophon*'-Beds are again found to lie about 150 feet above the base of the *Caninia*-Oolite.

The chief interest of these beds is, consequently, that they are the Q. J. G. S. No. 242.

fossiliferous equivalent of part of the unproductive Middle Shales and Dolomites of the Avon section.

Quarries in the *Seminula*-Zone :—

- (1) At the corner where the Clifton road branches off, immediately west of Longwood House, is a small quarry containing *Seminula* in abundance and traces of *Productus*, but no *Lithostroton*. This quarry lies due south of the small oolite-quarry north of Wraxall Piece, and the strike is again almost due east and west.

Calculation from the map proves that the beds here are about 350 feet normally above the base of the *Caninia*-Oolite; hence, assuming the general thickness of the *Caninia*-Series to be the same here as in the Avon section, this quarry should represent the very lowest beds of the Great Quarry.

- (2) The large lime-quarry in the *Seminula*-Oolite lies 900 yards east of Longwood House, at the side of the Clevedon road; a rough calculation from the map makes the beds in this quarry about 300 feet normally above those of the last quarry, and this accords well with the position of similar beds in the Avon section.

The other exposures mentioned below can only be referred to their correct stratigraphical position by the fossils found in them, since they lie isolated in those parts of the area where both strike and dip undergo rapid variation. Consequently, the results deduced from such exposures do not help to determine the zonal sequence, except in so far as they demonstrate the constant co-occurrence of the same forms.

### Detailed Description of Zones.

#### Tournaisian.

##### *Modiola*-Zone (M).

Lithological character.—Shales with thin limestones, capped by a thicker band of red limestones (Horizon *a*).

Exposure.—In the Failand section, near Millpond Farm.

Fauna.—An ostracod (? *Leperditia*), identical apparently with the one which is very common in the Avon section, is extremely abundant in one of the limestone-beds below Horizon *a*.

At Horizon *a* the red limestone is crowded with crinoidal débris. *Rhabdomeson* is abundant, and palatal teeth are not uncommon.

##### *Cleistopora*-Zone (K) and Horizon *β*.

Lithological character.—Shales with beds of limestone, the limestone predominating at the top.

## Exposures:—

- (1) In the Failand section (above Horizon  $\alpha$  up to, and including, the lower portion of the roadside-cutting west of the Horse-Race Quarry).
- (2) Roadside quarry near Failand-Hill House (Horizon  $\beta$ ).

## Faunal character:—

- (i) Of the *bassus*-subzone ( $K_1$ ).

All the fossils here mentioned were collected from the lowest part of the Failand section.

*Syringothyris* aff. *cuspidata*.

*Leptena analoga*.

*Orthotetes crenistria* (mut.  $K_1$ ).

*Chonetes* cf. *Buchiana*.

*Chonetes* cf. *crassistria*.

*Productus bassus*.

- (ii) Of the *octoplicata*-subzone ( $K_2$ ) and Horizon  $\beta$ .

The fossils here mentioned were collected only from the top of the zone in the Failand section, and in the quarry near Failand-Hill House.

*Clithyris Royssii* (mut.  $\beta$ ).

*Spirifer* aff. *clathratus*, in gradually-increasing numbers.

*Syringothyris* aff. *cuspidata*.

*Camarotachia mitcheldeanensis*.

*Leptena analoga*.

*Orthotetes crenistria*.

*Rhipidomella* aff. *Michelini*.<sup>1</sup>

*Productus* cf. *Martini*.

*Chonetes* cf. *Buchiana*.

*Chonetes* cf. *crassistria* (very abundant).

*Chonetes* cf. *hardrensis*.

*Zaphrentis*-Zone ( $Z$ ).

Lithological character.—Massive encrinital limestones which are thinner towards the bottom, where thin shales are intercalated among them.

i. *Clathratus*-subzone ( $Z_1$ ).

## Exposures:—

- (1) In the Failand section (the upper part of the roadside-cutting west of the Horse-Race).
- (2) Small exposures near Failand-Hill House.
- (3) A small quarry at the northern end of Fifty-Acre Plantation (east of the golf-links).

## Fauna:—

*Zaphrentis* aff. *Phillipsi*.

*Clithyris Royssii* (mut.  $\beta$ ).

*Spirifer* aff. *clathratus* and var. in great abundance.

*Syringothyris* aff. *cuspidata*.

*Leptena analoga*.

*Orthotetes crenistria* (mut.  $Z$ ).

*Rhipidomella* aff. *Michelini*.

*Chonetes* cf. *crassistria* (rare).

*Chonetes* cf. *hardrensis*.

ii. *Resupinata*-subzone (including the lowest part of Horizon  $\gamma$ ).

Exposure.—The 'Horse-Race Quarry' in the Failand section.

<sup>1</sup> Only found in the quarry near Failand-Hill House.

## Fauna:—

*Zaphrentis* aff. *cornucopiæ* (very abundant).  
*Zaphrentis* aff. *Phillipsi*.  
*Caninia* aff. *cylindrica* (at the top of the quarry, that is, in Horizon  $\gamma$ ).  
*Syringopora*  $\theta$ .  
*Spirifer* aff. *clathratus* (not uncommon at the base, rare at the top).  
*Syringothyris* aff. *cuspidata*.

*Syringothyris* aff. *laminosa*.  
*Clithyris glabristria* (abundant).  
*Reticularia* aff. *lineata*.  
*Leptena analoga*.  
*Orthotetes crenistria* (cf. var. *Kellii*)  
*Schizophoria resupinata* (abundant).  
*Rhipidomella* aff. *Michelini*.  
*Productus* aff. *Cora* (mut. *Z*).  
*Productus* aff. *pustulosus*.

The fossils of this subzone in the Failand area bear a remarkable resemblance both in forms and relative abundance to those at the same horizon in the Clevedon area (see pp. 225 *et seqq.*).

Comparison with the Avon section.—Up to the top of the *Zaphrentis*-Zone, the differences in the faunas of the two sections are too slight for special notice.

*Syringothyris*-Zone (C).

In ascending order the sequence is:—

- (1) Limestone with *Caninia* and *Zaphrentis*.
- (2) Limestone and shales poorly exposed, containing *Orthotetes*, *Chonetes*, and an occasional *Zaphrentis* (cf. *Caninia*).
- (3) Oolitic limestone (the *Caninia*-Oolite), practically unfossiliferous, resting upon a band in which *Orthotetes* and *Chonetes* aff. *papilionacea* teem, while *Syringothyris* aff. *laminosa* is not uncommon.
- (4) Thin shales and dolomitic limestones, poorly exposed.
- (5) The 'Bellerophon-Beds' (chiefly composed of massive fossiliferous oolite).

## Exposures:—

- (1) Forms the top of the Horse-Race Quarry in the Failand section.
- The upper part of (2) can be seen in the small quarry already described, which lies opposite the north-western corner of Wraxall Piece.
- (3) Comprises (a) the oolite-quarries at the top of the Failand section; (b) the shallow quarry west of Failand Inn; (c) the small quarry north of Wraxall Piece; and (d) the large quarry in the north-eastern corner of Wraxall Piece.
  - (4) Can be made out very imperfectly, along the side of the field-path leading from Failand Inn to the first *Bellerophon*-quarry.
  - (5) The first and second *Bellerophon*-quarries already described, and a disused quarry about 300 yards east of Failand Inn. The last-mentioned quarry lies a little north of the line joining the first and second *Bellerophon*-quarries, owing to the rise in the ground between those two quarries.



Faunal character.—The beds composing (1), (2), (3), and (4) have already been sufficiently discussed; their fossils agree precisely with those found at the same levels in other parts of the Bristol area.

The *Bellerophon*-Beds (5) are of great interest: firstly, because they occur at a horizon which is unfossiliferous in the Avon and Sodbury sections; and secondly, because they contain certain transitional forms between *Cyathophyllum* and *Caninia*. The fossils found in these beds are

*Orthotetes crenistria* (mut.).  
*Syringothyris cuspidata*.  
*Syringothyris* aff. *laminosa*.  
*Cyathophyllum*  $\phi$ .

‘*Chætetes*’ *tumidus* (a bryozoan).  
*Bellerophon* sp. (cf. *costatus*).  
*Euomphalus* sp.

and at the top—

*Seminula* aff. *ambigua*.  
*Seminula* aff. *ficoidea*.

*Productus* sp. (cf. *Productus*  $\theta$ ).

For convenience of reference, I have adopted the title ‘*Bellerophon*-Beds,’ since *Bellerophon* is extremely abundant in certain of the beds. *Cyathophyllum*  $\phi$  is also very abundant, and in chance-sections is easily mistaken for *Cyathophyllum Murchisoni*, a coral which, in the Bristol area, is only common in the *Dibunophyllum*-Zone.

The abundance of this *Cyathophyllum*, combined with the fact that specimens of *Seminula* and of a giganteid *Productus* can be picked up on the stone-heaps in the quarries, at first led me to believe that I was dealing with beds near the top of the Carboniferous-Limestone Series. But when I found that *Orthotetes* occurred in large numbers, and that the characteristic *Syringothyris* aff. *laminosa* as well as *Syringothyris cuspidata* were to be frequently met with, it became evident that my first view was incorrect. A very careful examination of the beds in place showed that the *Productus* was only to be found in the very topmost beds, and that *Seminula* was practically confined to the upper part of the quarry, whereas *Syringothyris* aff. *laminosa* occurred near the base.

I had also found the same beds in a quarry near West Tickenham (see ‘Isolated Exposures’ p. 231), and a vertical section of the *Cyathophyllum* seen *in situ* revealed the fact that the Failand *Cyathophyllum* is very different from *Cyathophyllum Murchisoni* (the former shows as marked a relationship to *Caninia* as the latter does to the Clisiophyllids). This view has been confirmed by the sections which I have had cut from specimens of *Cyathophyllum*  $\phi$  collected in the Failand quarries. Hence, on palæontological grounds, the *Bellerophon*-Beds must be assigned to the top of the *Syringothyris*-Zone, immediately below the base of the *Seminula*-Zone (that is, immediately below  $S_1$ ).

[It will be pointed out in the general summary that, if the Carboniferous Limestone is to be divided into two great systems, a lower (or Tournaisian) and an upper (or Viséan), the line of separation must be drawn at the top of the *Bellerophon*-Beds.]

The manner in which the same position for these beds has been fixed by stratigraphical reasoning has already been sufficiently described.

Comparison of the *Syringothyris*-Zone in the Failand area with other sections.—It has been sufficiently emphasized that, with the exception of the *Bellerophon*-Beds, there is a complete similarity, both lithological and palæontological, between the Failand and Avon development of this zone, but that the *Bellerophon*-Beds of the Failand area are represented in the Avon section by unfossiliferous shales and dolomites.

The fact that the *Bellerophon*-Beds are found in a precisely-similar development in the Clevedon area (near Tickenham) illustrates once more the essential similarity of that area with the Failand area.

### Viséan.

#### *Seminula*-Zone (S<sub>1</sub> & S<sub>2</sub>).

##### Exposures:

- |                |   |  |
|----------------|---|--|
| S <sub>1</sub> | { | (1) Thinly-bedded limestones, immediately above the <i>Bellerophon</i> -Beds in the first and second quarries. |
|                |   | (2) Massive limestones, in the small quarry west of Longwood House.  |
| S <sub>2</sub> | { | (3) Massive limestones, with a thick band of oolite, east of Longwood House.                                   |

Of these:

- (1) and (2) contain *Seminula ficoidea* and *Productus* θ (?), while *Lithostrotion* is rare or absent. Hence these exposures may be assigned to the base of the *Seminula*-Zone.
- (3) contains *Productus* aff. *Cora* (mut. S<sub>2</sub>), *Lithostrotion Martini*, and *Seminula ficoidea* in abundance. Hence (3) may be assigned to the middle of the *Seminula*-Zone.

Comparison with the Avon section.—As already pointed out, from stratigraphical considerations (2) probably corresponds to the very lowest beds in the Great Quarry, and (3) to the thick oolitic band which occurs near the top of the same quarry, while (1) represents part of the Middle Shales and Dolomites.

The absence of *Caninia cylindrica* var. *bristolensis* in the list of fossils from the lower part of this zone in the Failand area is probably due entirely to the fact that the horizon at which that fossil is abundant in the Avon section is here unexposed.

#### *Dibunophyllum*-Zone.

##### i. θφ-subzone (D<sub>1</sub>).

Lithological character.—Massive limestones, with shales and some rubbly limestones.

Exposure.—Two quarries near Flax-Bourton Station (nearly 1½ miles south, slightly east, of Failand Inn).

## Fauna:—

*Alveolites septosa.**Syringopora cf. geniculata.**Lithostrotion Martini* (cf. *L. affine*).*Cyathophyllum Murchisoni* and variants.Koninckophyllid *Cyathophyllum*.*Campophyllum* aff. *Murchisoni*.*Campophyllum* sp.

Clisiophyllids	{	<i>Dibunophyllum</i> $\theta$
		and <i>D. \phi</i> .
		<i>Clisiophyllum</i> $\theta$ .
		<i>Productus</i> 'giganteus.'
		<i>Productus hemisphericus</i> .
		<i>Chonetes</i> aff. <i>comoides</i> .
		<i>Cyrtina carbonaria</i> (mut.).

Comparison with other areas.—The general resemblance, as indicated by the above list of fossils and their relative abundance, amounts almost to identity; in fact, the Flax-Bourton quarries afford the best collecting-ground in the whole district for fossils of this subzone.

ii. *Lonsdalia*-Subzone ( $D_2$ ) is unexposed.

## (d) THE TYTHERINGTON SECTION.

Introduction.—Tytherington lies about 11 miles north  $30^\circ$  east of the Clifton Suspension-Bridge, and about  $4\frac{1}{2}$  miles north  $35^\circ$  west of Chipping Sodbury.

The Carboniferous Limestone (Lower or Tournaisian Division only) is now imperfectly exposed, in the cutting on the branch-line from Yate to Thornbury, between Grovesend and Tytherington; and a slightly-higher portion of the series (bottom-beds of the Upper or Viséan Division) can be examined in the limestone-quarries at Tytherington.

Prof. Lloyd Morgan<sup>1</sup> has given so excellent an account of the general geology of the district, and has illustrated his description by so good a map, that I can proceed without further introduction to the detailed palæontology of the section.

## Details of the Grovesend-Tytherington Section.

## Tournaisian.

*Modiola*-Zone (M).

Lithological character.—Shales and thin calcareous bands, capped by red limestone (Horizon  $\alpha$ ).

Exposure.—Entirely unexposed at the time of my visit, and so the beds could only be examined by unearthing them here and there. Prof. Lloyd Morgan estimates the shales and calcareous beds, below Horizon  $\alpha$  and above the Old Red Sandstone, at a little over 200 feet horizontal (which is equivalent to about 100 feet normal thickness). He records no fossils.

<sup>1</sup> 'The Geology of Tytherington & Grovesend' Proc. Bristol Nat. Soc. n. s. vol. vi (1888-91) p. 1. The Rev. H. H. Winwood has also contributed a paper on this cutting to the Cotteswold Naturalists' Field-Club, vol. ix (1888) p. 325, which is accompanied by a good section and explanatory diagrams.

### Horizon a.

Prof. Lloyd Morgan found the 'Bryozoa-Bed,' and I have verified its position. It contains *Rhabdomeson* and crinoid-débris, as in the Avon section.

### *Cleistopora*-Zone.

Lithology.—Shales and thin limestones.

Exposure.—The lower portion of the zone is entirely overgrown; the upper portion is partly, but very unsatisfactorily, exposed in a low cutting at the side of the railway-line.

Fauna:—

In the lower portion ( $K_1$ ) I have unearthed fragments containing *Orthotetes* and small *Chonetes* cf. *hardrensis*.

In the upper portion, *octoplicata*-subzone ( $K_2$ ):—

*Orthis* cf. *Leptena*, *Spirifer* aff. *clathratus*, and *Syringothyris* aff. *cuspidata* are very common.

*Productus* cf. *Martini* teems in certain beds near the top of the zone. *Cleistopora* aff. *geometrica* also is abundant near the top of the zone.

### *Zaphrentis*-Zone (Z).

#### i. *clathratus*-subzone ( $Z_1$ ).

Lithological character.—Somewhat shaly limestones.

Exposure.—Not well exposed, except near the top.

Fauna:—

*Spirifer* aff. *clathratus* and var., and *Orthotetes crenistria* (mut. Z) occur in enormous numbers.

*Cliothyris Royssii* (mut.  $\beta$ ) and *Camarotoechia mitcheldeanensis* occur occasionally.

*Cliothyris glabristria*, *Schizophoria resupinata*, *Rhipidomella* aff. *Michelini*, and *Zaphrentis* aff. *Phillipsi* are frequently met with at the top of the subzone.

#### ii. *resupinata*-subzone ( $Z_2$ ).

Lithological character.—Limestones.

Exposure.—Excellent exposed in a quarry at the side of the railway-line.

Fauna:—

##### (1) Extremely abundant:

*Zaphrentis* aff. *cornucopiæ*.

*Zaphrentis* aff. *Phillipsi*.

*Orthotetes crenistria* (mut. Z).

*Cliothyris glabristria*.

*Schizophoria resupinata*.

*Syringothyris* aff. *cuspidata*.

*Chonetes* cf. *hardrensis*.

##### (2) Scarce:

*Spirifer* aff. *clathratus* and *Rhipidomella* aff. *Michelini*.

##### (3) *Syringothyris* aff. *laminosa* is abundant at certain levels.

*Syringothyris*-Zone (C).

Sequence in ascending order :—

- (1) Thick encrinital, dolomitic limestones, comparatively unfossiliferous.
- (2) A very fossiliferous encrinital band (the 'sub-Oolite'). This band is non-oolitic in the lower portion, but oolitic in the upper.
- (3) A band of pure oolite (the 'Caninia-Oolite').
- (4) Thick dolomites, with subsidiary shales; unfossiliferous.

Exposures :—

- (1) is well exposed on each side of the cutting.
- (2) can be excellently worked in the lower portion of the oolite-quarry, west of the tunnel.
- (3) forms the upper part of this quarry, and also extends on each side of the cutting as far as the western mouth of the tunnel.
- (4) forms the sides and roof of the tunnel, and extends from the eastern mouth of the tunnel to near the end of the cutting.

Fauna :—

Corals :

*Zaphrentis* aff. *Phillipsi* occurs sparingly in (1) and in the lower part of (2); a single specimen has been found in the upper part of (2).

*Caninia*: one specimen only was found, namely, in the lower part of (2).

Brachiopods :

*Chonetes* cf. *hardensis* is extremely abundant in the lower part of (2), and is also met with in (1). This species is, as we ascend, gradually replaced by *Chonetes* aff. *papilionacea*, which teems in the upper part of (2).

*Spirifer* aff. *clathratus* and *Rhipidomella* aff. *Michelini* are found infrequently in the lower part of (2).

*Orthotetes crenistria* (cf. var. *Kellii*) occurs abundantly in the upper part of (2), in association with *Chonetes* aff. *papilionacea* and an occasional specimen of *Syringothyris* aff. *laminosa*. It extends on into (3).

*Productus* aff. *semireticulatus* occurs rarely in the upper part of (2).

*Euomphalus* occurs in considerable numbers in the upper part of (2) and in (3).

## Viséan.

*Seminula*-Zone (S).*Semireticulatus*-subzone (S<sub>1</sub>).

## Lithological character:—

- (1) Thick dolomites, with subsidiary shales (unfossiliferous), succeeded by
- (2) Massive limestones containing, at the top, two beds of highly-quartzose sandstone ('Firestone').

## Exposure:—

East of the tunnel, the upper part of the dolomites and shales is buried beneath a thick deposit of Dolomitic Conglomerate. The massive limestone forms the end of the cutting, and is well exposed in the large quarry which immediately follows on the side of the railway-line.

The stratigraphical relation of (1) and (2).—In the paper already referred to, Prof. Lloyd Morgan expresses the opinion that the continuity of the beds is broken between (1) and (2) by a reversed fault.<sup>1</sup>

Towards the end of the cutting the lowest beds of (2) certainly overlie the Dolomitic Conglomerate; and Prof. Lloyd Morgan explains this fact as due to a reversed fault by which

'the beds of Mountain Limestone have been thrust up, along their dip-faces, over basement-beds of the Trias.' (*Op. cit.* p. 6.)

Of the correctness of this explanation I have considerable doubt, for the following reasons:—

The lowest beds of (2) will be shown by palæontological evidence to belong to that portion of the *Seminula*-Zone which immediately succeeds the shales and dolomites in the Avon section.

Again, by calculating, from dip and distance, the position of the beds (2) at Tytherington above the base of the '*Caninia*-Oolite' exposed in the quarry west of the tunnel, and by comparing it with their position in the Avon section, it is seen that these beds actually occur very approximately in the position which they should occupy if the series were continuous. This conclusion merely proves that, if there be a fault, it can have no appreciable throw; but, seeing that a fault in which the fault-plane is coincident with the bedding-plane could have no throw, it does not disprove the existence of such a fault as Prof. Lloyd Morgan suggests.

At the end of the Carboniferous-Limestone section at Sodbury, however, where the limestone comes into contact with Dolomitic Conglomerate, there is a similar instance of limestone-beds overlying a mass of Dolomitic Conglomerate, except that here the Conglomerate can be clearly seen to rest upon the limestone-floor and to fill in a recess in the limestone-cliff.

The Tytherington phenomenon seems to me to be a similar case, and to be even easier of interpretation, for the shaly beds (1), just

<sup>1</sup> Proc. Bristol Nat. Soc. n. s. vol. vi (1888-91) p. 13.

below the massive limestone (2), would have been easily eaten back at the base of the ancient cliff, leaving an overhanging wall formed by the lowest beds of (2). The subsequent infilling of this recess by Dolomitic Conglomerate would exactly produce the phenomenon described.

**Fauna:—**

<i>Productus</i> aff. <i>Coramut.</i> C, Pr. 0, and Pr. aff. <i>semireticulatus</i> .	<i>Lithostrotion Martini</i> & varieties.
<i>Seminula ficoidea</i> and allied forms.	<i>Caninia</i> sp. <i>Syringothyris</i> aff. <i>laminosa</i> (?).

NOTES.—*Lithostrotion* is rare at the base, but becomes very abundant at the top. *Caninia* was determined from rather unsatisfactory sections seen *in situ* just below the beds of sandstone. *Syringothyris* aff. *laminosa* (?) is merely a suggested correction of '*Spirifer octoplicata*,' which is recorded by the Rev. H. H. Winwood from the lower sandstone-bed.

The presence of *Productus* aff. *semireticulatus* and of *Caninia*, the rarity of *Lithostrotion* in the lowest beds and its increasing abundance above, together with the presence of a Spiriferid of the *laminosa*-type, seem to me to afford sufficient evidence for assigning these beds to S<sub>1</sub>.

**Upper *Seminula*-Zone (S<sub>2</sub>).**

The upper part of the large quarry may be referred with the greatest probability to the middle of the *Seminula*-Zone. As is usual in other sections at this level, there is a thick band of fossiliferous oolite.

**Fauna:—**

<i>Seminula ficoidea</i> and allied forms.	<i>Lithostrotion Martini</i> .
<i>Productus</i> aff. <i>Cora</i> .	<i>Syringopora</i> sp.
<i>Productus</i> aff. <i>hemisphericus</i> .	Clisiophyllid (rare).
<i>Chonetes papilionacea</i> .	

The quarry north of the railway, near the station, contains the same fossils, and is also undoubtedly in the *Seminula*-Zone.

Comparison of the Tytherington Section with those of the Avon, Sodbury, and Failand.

**I. Characters common to all four sections.**

- (1) The fauna of Horizon *a* (the 'Bryozoa-Bed') is identical.
- (2) *Orthotetes crenistria* (in its mutations) is predominant throughout the Tournaisian, but becomes extremely scarce in higher beds.
- (3) *Spirifer* aff. *clathratus* reaches its maximum (at which point it is enormously abundant) and declines, before *Oliothyris glabristria* and *Schizophoria resupinata* attain their maxima.
- (4) *Schizophoria resupinata* and *Oliothyris glabristria* reach a maximum together, and both are very abundant at this point.

- (5) *Zaphrentis* attains its maximum at, or a little above, the maximum of *Cliothyris glabristria*.
- (6) *Chonetes* cf. *hardrensis* yields its predominance to *Chonetes papilionacea* from the lower part of the *Syringothyris*-Zone onwards.
- (7) *Syringothyris* aff. *laminosa* enters in the *resupinata*-subzone, and is specially characteristic of the *Syringothyris*-Zone.
- (8) *Syringothyris cuspidata*, in its large and most characteristic form, attains a maximum at the top of the *resupinata*-subzone.
- (9) *Lithostroton* is, at first, scarce at the base of the *Seminula*-Zone (that is, in the lower part of  $S_1$ ).
- (10) *Productus*  $\theta$  is the commonest representative of the genus in the lower part of the *Seminula*-Zone.

II. Characters shared by the Sodbury, Avon, and Tytherington sections.<sup>1</sup>

- (1) *Caninia cylindrica* var. *bristolensis* is characteristic of the top of  $S_1$ .
- (2) *Lithostroton Martini* increases from scarcity to extreme abundance as we ascend through  $S_1$ .

III. Characters shared by the Avon, Failand, and Tytherington sections.<sup>2</sup>

*Cleistopora* aff. *geometrica* attains its maximum in the upper part of the *Cleistopora*-Zone.

IV. Characters common to the Sodbury and Tytherington sections.

*Caninia* is scarce or absent immediately above the *resupinata*-subzone, and so Horizon  $\gamma$  cannot be distinguished.

V. Characters common to the Avon and Tytherington sections.

A *Spirifer* of the *laminosa*-type is characteristic of the top of  $S_1$ .

VI. Characters of especial interest in the Tytherington section.

- (1) *Schizophoria resupinata* is more frequently met with at the top of the *clathratus*-subzone than appears to be the case in any of the other sections.
- (2) *Zaphrentis* and *Caninia* occur in the 'sub-Oolite' (compare a similar occurrence at Failand and Southmead).
- (3) *Chonetes* cf. *hardrensis* is abundant in the lower part of the 'sub-Oolite.' (The species occurs on the same horizon at Failand and Southmead.)
- (4) *Rhipidomella* aff. *Michelini* and *Spirifer* aff. *clathratus* have been found, though very sparingly, as high up as the bottom of the 'sub-Oolite.'

<sup>1</sup>  $S_1$  is very incompletely exposed at Failand.

<sup>2</sup> Unobserved at Sodbury, probably on account of the pooriness of the exposure. See p. 205.



As might have been anticipated from its geographical position, the section at Tytherington is most closely related to that at Sodbury, both palæontologically and lithologically.

The scarcity of *Caninia* just above the *resupinata*-subzone, where it is so abundant in the southern part of the Bristol area, is a feature common to both sections, while the relative abundance of the brachiopods is almost identical in the two sections.

Again, the increase in the predominance of dolomites over shales in the middle of the Carboniferous-Limestone Series which was noticed in the Sodbury section is, at Tytherington, a very striking feature. So massive do these dolomites become in this section that the tunnel has been bored through them, and left unbricked.

A minor feature of some interest is the occurrence of beds of highly-quartzose sandstone, both at Sodbury and at Tytherington, in the lower part of the *Seminula*-Zone; at Sodbury these sandstones occur at the base of  $S_1$ , while at Tytherington they occur near the top of that subzone.

#### (e) THE CLEVEDON AREA.

Clevedon lies  $10\frac{1}{4}$  miles west, slightly south, of Clifton Suspension-Bridge, on the south side of the Severn estuary.

##### Tournaisian.

Exposures and lithological character:—

- I. The sequence, as exposed in ascending order along the coast, from north-east to south-west.
  - (a) The *Oleistopora*-Zone, composed of shales and subsidiary limestones, is exposed on the foreshore between the pier and Clevedon Bay.
  - (b) The *clathratus*-subzone (massive limestone) is excellently shown in the cliffs and on the foreshore, extending from Clevedon Bay to a little south of Littleharp Point.
  - (c) The *resupinata*-subzone forms the cliffs at Salthouse Point.
  - (d) The uppermost beds of the *Zaphrentis*-Zone, including Horizon  $\gamma$ , occur near the Pill, where specimens of *Zaphrentis* and *Caninia*, washed out of the cliffs, can be picked up in hundreds.
- II. The sequence, as exposed in ascending order along the path on Strawberry Hill, the Carboniferous ridge which lies about three quarters of a mile east of the beach, west of the road from Clevedon to Portishead. Starting at the north of the hill, where the Pennant Grit rests upon the Carboniferous Limestone, and proceeding southward, the zones enumerated below are met with in the following order:—
  - (a) The uppermost beds of the *clathratus*-subzone.
  - (b) The *resupinata*-subzone, chiefly characterized by the predominance of *Zaphrentis* aff. *Phillipsi* (the subzonal index being scarce).

- (c) The uppermost beds of the *Zaphrentis*-Zone, including Horizon  $\gamma$ . These beds are well seen in a quarry east of the Fir Wood, and here *Zaphrentis* and *Caninia* occur together in great abundance.
- (d) The lowest part of the *laminosa*-subzone. This is represented by a few beds at the very top of the quarry just mentioned. These beds are pale yellow and highly dolomitic; they are friable and soft, and do not readily effervesce in acid; they contain few fossils beyond fragments of crinoids, and will be referred to as the '*laminosa*-dolomites.'

### III. Exposures in Horizon $\gamma$ and the lowest beds of the *laminosa*-subzone.

There are five such exposures, which lie (after making corrections for differences of contour) upon a line of strike running west  $25^\circ$  south; the distance between the quarries at the two ends of the line is about  $1\frac{1}{2}$  miles. They are, tracked from east-north-east to west-south-west:—

- (1) An exposure on the west side of the Portishead road, cut into the base of Strawberry Hill under the path already followed.
- (2) The quarry, already described, east of the Fir Wood on Strawberry Hill:—Upper *resupinata*-subzone, Horizon  $\gamma$ , and the bottom of the '*laminosa*-dolomites.'
- (3) A roadside exposure on the north side of High-Dale Avenue:—Upper part of Horizon  $\gamma$  and a long series of the '*laminosa*-dolomites,' which here contain bands of *Chonetes* and *Orthotetes* at frequent intervals.
- (4) Hangstone Quarry (at the foot of Hangstone Hill):—'*Laminosa*-dolomites' with bands of the same fossils exposed on the dip-slopes.
- (5) A quarry near the Old Church, south of Salthouse:—Upper *resupinata*-subzone and Horizon  $\gamma$  as well as the lowest part of the '*laminosa*-dolomites.'

### IV. Exposures on Court Hill, east of the Portishead road, facing Strawberry Hill on the west.

On the crest of the hill Pennant Grit (worked in the large Conygar Quarries) comes into contact with the Carboniferous Limestone.

Tracking the beds southward down the slope of the hill (at the foot of which lies All Saints' Church), and then proceeding along the road to Court Farm, the following zones are met with:—

- (a) The *resupinata*-subzone, well displayed on the slope wherever the rocks are uncovered.
  - (b) Horizon  $\gamma$  and the '*laminosa*-dolomites' are concealed.
  - (c) The *Caninia*-Oolite occurs behind Court Farm.
- The sequence is identical with that on Strawberry Hill.

V. The sequence at Walton Castle. This locality is a little more than three quarters of a mile due north of the quarry on Strawberry Hill, and can be reached by turning off the Portishead road along Holl Lane.

- (a) The upper part of the *Cleistopora*-Zone and the lower beds of the *clathratus*-subzone are well exposed to the east of Castle Farm.
- (b) The *resupinata*-subzone is exposed at the top of Walton-Castle Hill and in a quarry near the western end of Holl Lane.
- (c) Horizon  $\gamma$  and the 'laminosa-dolomites' are not exposed.
- (d) The *Caninia*-Oolite is splendidly exposed in the large lime-quarries on each side of Holl Lane, between the Castle and the Portishead road.

#### Fauna<sup>1</sup>:—

##### *Cleistopora*-Zone.

*Cleistopora* aff. *geometrica* has been found in Clevedon Bay (that is, in the upper part of the zone). There is a specimen from this locality in the Natural History Museum, South Kensington.

*Spiriferina octoplicata* is very common in the upper beds near Castle Farm.

##### *Clathratus*-subzone.

*Spirifer* aff. *clathratus* and var. occur in enormous abundance, and are associated with the same forms as elsewhere.

*Zaphrentis* is extremely rare.

##### Lower *resupinata*-subzone.

*Zaphrentis* aff. *Phillipsi* is the dominant representative of the genus.

*Cliothyris glabristria* is uncommon, although I have found it both on Strawberry Hill and Court Hill.

##### Upper *resupinata*-subzone and Horizon $\gamma$ .

*Syringopora*  $\theta$  is a characteristic and easily-distinguished form.

*Zaphrentis* aff. *cornucopiae* becomes the dominant species, but *Z.* aff. *Phillipsi* is still common.

*Caninia cylindrica* and its mutations are abundant, and mark out Horizon  $\gamma$ .

*Syringothyris* aff. *laminosa* and *Michelinia* occur somewhat frequently.

##### *Laminosa*-subzone.

Bands of *Orthotetes* and *Chonetes* aff. *papilionacea* are well seen in the 'laminosa-dolomites,' especially in Hangstone Quarry.

The *Caninia*-Oolite contains the usual fossiliferous basal beds, in which *Orthotetes* and *Chonetes* are abundant.

<sup>1</sup> Reference is made here only to points of especial interest.

The most interesting points in the Clevedon development are as follows:—

(1) The great abundance of *Zaphrentis* in the *resupinata*-subzone and the strong demarcation of Horizon  $\gamma$  by the abundance of *Caninia cylindrica*.

(2) The dominance of *Zaphrentis* aff. *Phillipsi* in the lower part of the *resupinata*-subzone, and of *Zaphrentis* aff. *cornucopiae* in the upper.

(3) The occurrence at Horizon  $\gamma$  of transitional forms between *Zaphrentis*, *Caninia*, and *Cyathophyllum* (compare Spring Cove).

(4) The occurrence of a characteristic form of *Syringopora* in the upper part of the *Zaphrentis*-Zone. This form is found at the same horizon in the Failand, Sodbury, and Avon sections.

(5) The light which the accurate determination of the age of the Carboniferous Limestone that surrounds or is included in the Pennant Series, in the Clevedon and Clapton areas, is likely to throw upon the relation of the Coal-Measures to the Carboniferous Limestone in the district. So far as I have yet been able to form an opinion, a considerable unconformity seems the only possible solution.

#### (f) THE PORTISHEAD DISTRICT.

Portishead Railway-Station lies  $4\frac{1}{4}$  miles north-east of Clevedon Station, and  $6\frac{1}{2}$  miles west  $20^\circ$  north of the Clifton Suspension-Bridge.

The Carboniferous-Limestone ridge stretches continuously along the west side of the road, from Clevedon to near Portishead, where it is abruptly interrupted; but the Carboniferous Limestone again reappears on the foreshore, in front of the Esplanade, and also extends in a west-and-east ridge, from Battery Point to Portishead Dock.

The Portishead district has been briefly described by Buckland & Conybeare,<sup>1</sup> and later, in considerable detail, by Prof. Lloyd Morgan.<sup>2</sup> The last-named author dissents from the conclusions of the earlier observers in several important points, only one of which, however, concerns my present object, namely, the interpretation of the beach-sequence near Battery Point.

The facts, as I read them, are as follows:—Beds identical with the Avon 'Bryozoa-Beds' emerge from beneath the alluvium at the northern end of Woodhill Bay, and form a low cliff; these beds bend completely over. For a few yards north of this roll, there is a confused jumble in which no arrangement can be detected. Still proceeding northward, we next meet with four or five small, sharp flexures (broken in places) in a series of shales and thin limestones. In these beds *Cleistopora* is very common. The last of the small

<sup>1</sup> 'Observations on the South-Western Coal-District of England' Trans. Geol. Soc. ser. 2, vol. i (1824) p. 210.

<sup>2</sup> Proc. Bristol Nat. Soc. n. s. vol. v (1885-88) p. 17.

flexures rolls over at a small angle to the north, and the Palæozoic rocks are concealed from view for about 100 yards. They again emerge in the cliff at Battery Point, and their age can here be definitely fixed as Horizon  $\beta$ .

The abundance of *Cleistopora* in the flexed beds indicates the upper part of  $K_1$  and the small distance between these beds and Horizon  $\beta$ , at Battery Point, confirms this conclusion. Hence, we have the 'Bryozoa-Beds' (just below  $K_1$ ) in juxtaposition with the upper part of  $K_2$ . This phenomenon necessitates a big fault, and, if we assume a reversed fault to separate Horizon  $\alpha$  (the 'Bryozoa-Beds') from the flexed beds of the upper part of  $K_2$ , we have a simple explanation of the series of small sharp flexures. This view is in partial agreement with that expressed by Buckland & Conybeare more than eighty years ago.<sup>1</sup>

### Tournaisian.

Exposures and lithological character:—

Horizon  $\alpha$  (the 'Bryozoa-Bed') is well shown in a low cliff of red limestone on the beach.

The upper part of the *Cleistopora*-Zone can be examined on the foreshore, between the outcrop of Horizon  $\alpha$  and Battery Point. The *clathratus*-subzone is excellently displayed at Battery Point, and in the cliffs for some distance east of the point.

The *resupinata*-subzone, extremely rich in *Zaphrentis*, is well seen in two quarries in the Portishead-Clevedon ridge, that is: (1) A quarry, cut into the side of the Big Weston Wood, which can be seen from the road; and (2) A disused quarry a short distance up Nightingale Vale (past the large quarry referred to below).

Horizon  $\gamma$  and the '*laminosa*-dolomites' can only be made out in poor exposures at the side of Nightingale Vale, between the *resupinata*-quarry and the large quarry already mentioned. The *Caninia*-Oolite is well seen in this large quarry; it has the fossiliferous band at the base, and is capped by compact dolomites.

Fauna:—

### *Modiola*-Zone.

Horizon  $\alpha$  (the only part of the zone that is exposed) occurs, as already stated, in a low cliff. The beds in the cliff are remarkably similar to those at the same horizon in the Avon section, and the fossiliferous strata contain an identical assemblage of organisms: namely, prolific erinoid-débris with abundant *Rhabdomeson*, but very few other fossils.

The title 'Bryozoa-Bed' is well deserved, but the abundance of bryozoans has been absurdly overstated. *Rhabdomeson* is the only bryozoan that is at all common, and this fossil is not more abundant here than it is in certain beds in the *Cleistopora*-Zone

<sup>1</sup> Trans. Geol. Soc. ser. 2, vol. i (1824) p. 246.

<sup>2</sup> Only the most interesting points are noticed.

(see immediately below). No doubt the fragments of crinoids have been mistaken for bryozoans, on account of their peculiar microscopic structure.<sup>1</sup>

*Cleistopora*-Zone. (Upper K<sub>2</sub> only.)

*Cleistopora* aff. *geometrica* is abundant in certain beds.

A very short distance north of the cliff already described, and lying in a small syncline, is a red earthy limestone crowded with *Rhabdomeson*, crinoid-débris, and small gasteropods; the following fossils<sup>2</sup> occur abundantly in this bed:—

- Palatal teeth.
- Scaphopod ..... *Dentalium* (?).
- Pteropods ..... *Hyalithes*, *Tentaculites*.
- Gasteropods ..... *Loxonema*, *Macrocheilus* (?), *Straparollus*,  
*Bellerophon*; *Pleurotomaria* (at least  
two species); *Murchisonia* (two or  
three species).
- Opisthobranch ... *Actæonina*.
- Brachiopods ..... *Syringothyris* aff. *cuspidata*, *Orthotetes*  
aff. *crenistris*, *Lingula mytiloides*.
- Ostracod ..... *Leperditia* (?).
- Crinoids ..... Débris probably of several forms.

*Clathratus*-subzone.

This subzone presents its usual features.

Horizon β contains *Spiriferina octoplicata*.

*Resupinata*-subzone.

The following fossils have been obtained from the quarry in  
Big Weston Wood:—

- |  |                          |  |
|--|--------------------------|--|
| <i>Zaphrentis</i> aff. <i>cornucopiæ</i>       | } extremely<br>abundant. | <i>Orthotetes crenistris</i> .                 |
| <i>Zaphrentis</i> aff. <i>Phillipsi</i>        |                          | <i>Leptena analoga</i> .                       |
| <i>Spirifer</i> aff. <i>clathratus</i> (rare). |                          | <i>Schizophoria resupinata</i> .               |
| <i>Syringothyris</i> aff. <i>cuspidata</i> .   |                          | <i>Rhipidomella</i> aff. <i>Michelini</i> .    |
| <i>Syringothyris</i> aff. <i>laminosa</i> .    |                          | <i>Productus</i> aff. <i>semireticulatus</i> . |
| <i>Cliothyris glabristria</i> .                |                          |  |

The simultaneous occurrence of *Cliothyris glabristria* and *Schizophoria resupinata*, together with the abundance of *Zaphrentis* and the entrance of *Syringothyris* aff. *laminosa*, serves to fix the position of the beds with complete definiteness, and to emphasize the essential similarity of this subzone throughout the Bristol area.<sup>3</sup> (Compare the Avon and Sodbury sections.)

*Laminosa*-subzone.

At the base of the *Caninia*-Oolite, *Orthotetes* and *Chonetes* are abundant, in association with an occasional specimen of *Syringothyris* aff. *laminosa*.

<sup>1</sup> Dr. F. A. Bather has kindly confirmed the fact, that the most abundant organisms seen in a thin section of the Avon 'Bryozoa-Bed' are fragments of crinoids.

<sup>2</sup> The determination of the genera may need revision, as I have no special knowledge of Carboniferous gasteropoda. I have to thank Mr. W. H. Wickes for his kindness in presenting me with my best material.

<sup>3</sup> Large palatal teeth, similar to those found in the same subzone in the Avon section, are occasionally obtained from this quarry.

## (ii) Isolated Exposures in the Bristol Area.

## (A) In the Clifton-Clevedon Ridge.

## I. Between the Clifton and Failand Areas.

## (1) Near Cadbury Camp (3 miles east of Clevedon Railway-Station).

- (a) The upper *Zaphrentis*-Zone is seen in small exposures, at the side of the road which runs along the crest of the ridge.

*Zaphrentis* is abundant, associated with the same brachiopods as in the Clevedon area, and it is this abundance that immediately fixes the horizon.

- (b) The lower *laminosa*-subzone (the '*laminosa*-dolomite') is well shown in a quarry on the southern flank of the ridge, north-west of Tickenham (halfway between Cadbury Camp and East Clevedon).

Bands of *Ononotetes* aff. *papilionacea* and *Orthotetes crenistria* fix the horizon.

- (c) Horizon  $\delta$  (the '*Bellerophon*-Beds') is splendidly displayed in a quarry a little north-west of Tickenham, on the north side of the Clevedon road, at the western end of the village of Middletown. This quarry is cut into the southern side of a lower ridge, which runs parallel to the main ridge on its south side, and is separated from the main ridge by a depression. This depression is doubtless caused by the more rapid denudation of the thick '*laminosa*-dolomites,' of the '*Caninia*-Oolite,' and of a thin series of the superjacent '*Caninia*-Dolomites.' From this quarry I have obtained:—

*Chaetetes* <sup>1</sup> *tumidus*.

*Cyathophyllum*  $\phi$ .

*Syringopora* sp.

*Syringothyris* aff. *cuspidata*.

*Syringothyris* aff. *laminosa*.

*Seminula* sp.

(*Athyris*) sp.

*Orthotetes crenistria* (a mutation

identical with that at Horizon  $\delta$ , Failand, and cf. var. *Kellii*).

*Productus* sp. (cf. *Productus*  $\theta$ ).

*Productus* aff. *semireticulatus* (mut.).

*Reticularia* sp.

*Dielasma* sp.

*Bellerophon* sp. (cf. *costatus*).

*Euomphalus* sp.

The above list leaves no doubt as to the identity of the horizon.

- (d) Clapton-in-Gordano.—Clapton lies nearly 6 miles west (slightly north) of the Clifton Suspension-Bridge. The quarry occurs in an isolated mass of Carboniferous Limestone which lies just north of the road from Portbury to Clevedon, about a quarter of a mile east of Clapton Church. This mass of limestone comes into contact with the Pennant Series on the south, but on all other sides it is surrounded by Triassic rocks. There are several other smaller masses <sup>1</sup> of Carboniferous Limestone in the

<sup>1</sup> In the Geological Survey Memoir ('Geology of East Somerset & the Bristol Coalfields' 1876, p. 21) these small, isolated masses are merely mentioned, with the remark that it is difficult to account for their presence. They are accounted for by Prof. Lloyd Morgan as the result of a 'flat-lying fault' which sliced and heaved the Carboniferous Limestone, subsequent denudation producing the isolated patches, Proc. Bristol Nat. Soc. n. s. vol. v (1885-88) p. 15.

immediate neighbourhood of Clapton, at least one of which is entirely surrounded by the Pennant Series (see Sheet 19, Geol. Surv. 1-inch map).

The quarry is on Horizon  $\beta$ , as indicated by the following fossils:—

<i>Zaphrentis</i> aff. <i>Phillipsi</i> .	} Abundant.	<i>Spirifer</i> aff. <i>clathratus</i> . Abundant.
<i>Spiriferina octoplicata</i> .		<i>Orthotetes crenistria</i> .
<i>Cliothyris Royssii</i> (mut.).		<i>Syringothyris</i> aff. <i>cuspidata</i> .

It is, in my opinion, entirely out of the question that there is a complete sequence from the Tournaisian up to the Coal-Measures anywhere in the Clapton-Clevedon-Portishead area. There is nowhere sufficient space between the outcrops of these two formations to allow of the complete sequence being developed; in fact, I have seen no Viséan strata north of Tickenham Church.

I am strongly inclined to believe that there is, in this region, evidence of post-Tournaisian upheaval and denudation, and that the area was not again submerged until the Coal-Measures were laid down in a narrow inlet, bounded on the west by the Clevedon-Portishead ridge and on the south by the western part of the Clevedon-Failand ridge. Within this inlet, the masses of Carboniferous Limestone in the Clapton district stood up as small islands.

- (e) Tickenham.—The lower beds of the *Seminula*-Zone can be made out in a field immediately east of Tickenham Church. Here I found *Productus* sp. (cf. *P. θ*), *Seminula ficioidea*, and *Orthotetes crenistria* (mut.).

We may unhesitatingly compare these beds with the lowest beds in Dod's Quarry (see p. 241); a result in complete accord with their stratigraphical position. I strongly doubt the completeness of the sequence between these beds (of lowest Viséan age) and the Coal-Measures which are found a few yards farther south. There is certainly no room for the Upper *Seminula*-Zone, the *Dibunophyllum*-Zone, and the Millstone-Grit.

- (2) A quarry near Moat-House, north of the Clevedon road,  $1\frac{3}{4}$  miles west of Failand Inn.

Upper *clathratus*-subzone and Lower *resupinata*-subzone.

From this quarry I have obtained:—

<i>Zaphrentis</i> aff. <i>Phillipsi</i> .	<i>Rhipidomella</i> aff. <i>Michelinii</i> .
<i>Cliothyris glabristria</i> .	<i>Schizophoria resupinata</i> .
<i>Cliothyris</i> sp. (?).	<i>Productus</i> cf. <i>Martini</i> .
<i>Spirifer</i> aff. <i>clathratus</i> .	<i>Productus</i> aff. <i>pustulosus</i> .
<i>Syringothyris</i> aff. <i>cuspidata</i> .	<i>Productus</i> aff. <i>semireticulatus</i> .
<i>Syringothyris</i> aff. <i>laminosa</i> .	<i>Chonetes</i> cf. <i>hardrensis</i> .
<i>Orthotetes crenistria</i> (mut. Z).	<i>Chonetes</i> aff. <i>papilionacea</i> .
<i>Leptæna analoga</i> .	

Note.—*Cliothyris glabristria* and *Rhipidomella* aff. *Michelinii* are extremely abundant; *Zaphrentis* and *Schizophoria* are rare.



## II. Between the Failand Area and the Avon Section.

- (1) A quarry near Abbot's Leigh, north of the Portishead road about  $1\frac{1}{2}$  miles from the Clifton Suspension-Bridge.

*Zaphrentis*-Zone.*Clathratus*- and *resupinata*-subzones.

In the lower beds of the quarry

*Spirifer* aff. *clathratus* and var. crowd the beds, and are associated with the following fossils in great abundance:—

*Syringothyris* aff. *cuspidata*,

*Orthotetes crenistria* (mut. Z),

*Leptena analoga*, and

*Chonetes* cf. *hardensis*.

*Cliothyris Royssii* (and mut. β),

*Camarotoechia* aff. *mitchelleanensis*,

*Productus* cf. *Martini*, and

*Rhipidomella* aff. *Michelini*

} are also common.

In the higher beds

*Zaphrentis* aff. *Phillipsi* is not uncommon.

*Cliothyris glabristria* is abundant, and a single specimen of

*Schizophoria resupinata* was discovered.

*Reticularia* aff. *lineata*, *Productus* cf. *Martini* occur, and

*Chonetes* cf. *laquessiana* is extremely abundant.

The beds resemble so closely those in the Avon section that no further discussion of this horizon is necessary.

- (2) Exposures near Long Ashton,<sup>1</sup> about  $1\frac{3}{4}$  miles south-west of the Clifton Suspension-Bridge.

In the grits which are usually considered to form the base of the Millstone-Grit *Productus* aff. *scabriculus* is fairly common, affording evidence of Horizon ε.

## (B) In the Clifton-Westbury-King's Weston Ridge.

- (1) Exposures on Durdham Downs.

- (a) In the broken ground south of the Reservoir. The lower *Seminula*-Zone is shown, as evidenced by the following fossils:—

*Caninia cylindrica* var. *bristolensis*.

*Productus* θ.

*Lithostroton Martini* and var.

*Seminula ficoidea*.

*Syringopora* cf. *distans*.

Also occasional specimens of *Orthotetes crenistria* (mut.) and

*Euomphalus* sp.

- (b) In the disused quarry at the top of Pembroke Road, the upper part of the *Seminula*-Zone is shown, as evidenced by:—

*Seminula* spp.

*Productus* 'giganteus.'

*Lithostroton Martini*, and

an occasional specimen

of *Clisiophyllum* θ.

<sup>1</sup> I have not personally examined the section, but localized specimens are in the collection at University College, Bristol.

- (c) Along the edge of the Downs, between the top of Pembroke Road and the Fountain, higher beds come in very gradually, as the southern edge of the Downs nearly coincides with a line of strike. Between College Road and the Fountain, the lowest part of the *Dibunophyllum*-Zone is shown, as evidenced by:—

<i>Lithostrotion Martini.</i>		<i>Dibunophyllum</i> spp.
<i>Syringopora</i> cf. <i>distans</i>		<i>Productus</i> 'giganteus.'
<i>Cyathophyllum Murchisoni.</i>		

These exposures merely confirm the sequence in the Avon section, and could have been foretold by continuing the lines of strike across the map.

(2) In Westbury Park, near Cold-Harbour Farm.

The Carboniferous Limestone is here exposed, dipping at a high angle, and the Rhætic rests unconformably upon it.

The *Seminula*-Zone (probably the lower part) is shown by—  
*Seminula* sp. and *Productus* θ (?).

(Fossils are scarce and poor, and the exposure is very small.)

(3) Near Southmead (three quarters of a mile east of Westbury-on-Trym).

The *laminosa*-subzone is excellently shown in the large quarries near Southmead. The following divisions are exhibited (in ascending order):—

The 'laminosa-dolomite' (here only slightly dolomitic, but conspicuously encrinital).

The 'Caninia-Oolite,' resting upon an extremely-fossiliferous band (as is usual throughout the Bristol area).

The lowest beds of the 'Caninia-Dolomites' (thinly-bedded compact limestones).

The following fossils have been collected, from the top of the *laminosa*-dolomite and from the base of the oolite:—

<i>Syringothyris</i> aff. <i>laminosa</i> (common).		<i>Chonetes</i> cf. <i>hardrensis</i> (not common).
? <i>Seminula</i> sp. (rare).		<i>Chonetes</i> aff. <i>papilionacea</i> and <i>Ch.</i> cf. <i>comoides</i> (extremely abundant).
<i>Orthis crenistria</i> , muts. Z & C (very abundant).		A Zaphrentid (cf. <i>Caninia</i> ) is occasionally seen, sectioned <i>in situ</i> .
? <i>Rhipidomella</i> aff. <i>Michelini</i> (rare).		

This horizon is of considerable interest, since it shows the first appearance of a Viséan fauna at the top of the Tournaisian.

The cornute Zaphrentid, *Chonetes* cf. *hardrensis*, *Rhipidomella* aff. *Michelini*, and the convex, grooved *Orthis* (cf. var. *Kellii*), are characteristic survivors from the Zaphrentis-Zone.

*Seminula* sp., *Chonetes papilionacea* in its convex, thick-shelled mutation (*Ch.* cf. *comoides*), and the mutation of *Orthis crenistria* which exhibits strong periodicity of ribbing, combined with conspicuous reticulation, are characteristic of the Viséan stage.

*Syringothyris* aff. *laminosa* is characteristic of the whole *Caninia*-Zone, and is associated at one end of the zone with a typical Tournaisian fauna, at the other with a typical Viséan fauna.

This horizon exhibits the same characteristics in the Tytherington section, at Wickwar, and at Cromhall.

- (4) Brentry Hill, three quarters of a mile north of Westbury-on-Trym. (Two quarries, one on the main road to the Passages, the other on the branch road to Charlton.)

The upper part of the *Seminula*-Zone and the base of the *Dibunophyllum*-Zone are shown, as evidenced by:—

<i>Seminula ficoidea</i> and <i>S. cf. ambigua</i> (mut. <i>S.</i> <sub>2</sub> ).		<i>Productus</i> aff. <i>hemisphericus</i> .
<i>Productus</i> aff. <i>Cora</i> .		<i>Orthotetes crenistria</i> (mut. <i>D</i> ) (rare). <i>Lithostrotion Martini</i> and variants.

These fossils abound throughout the lower and middle beds, indicating the Upper *Seminula*-Zone.

The concretionary structure is splendidly shown in the uppermost beds of this zone, and some layers almost exactly resemble Cotham Marble. In the upper beds we find:—

<i>Alveolites septosa</i> .		<sup>1</sup> <i>Lithostrotion Martini</i> (mut. towards <i>L. affine</i> ).
<i>Cyathophyllum Murchisoni</i> .		<sup>1</sup> <i>Dibunophyllum</i> $\theta$ and <i>Dib. p.</i> <i>Clisiophyllum</i> $\theta$ .
<sup>1</sup> <i>Syringopora</i> cf. <i>distans</i> and <i>S. cf. geniculata</i> .		

These fossils definitely indicate the  $\theta\phi$ -subzone.

- (5) Blaize-Castle Wood, near Henbury.

An exposure by the side of the Rhododendron Walk yielded the following corals:—

<i>Lithostrotion irregulare</i> .		<i>Syringopora</i> cf. <i>distans</i> .
<i>Lithostrotion Martini</i> and mutation (cf. <i>L. affine</i> ).		<i>Cyathophyllum Murchisoni</i> var. <i>Axophyllum</i> $\theta$ .
<i>Lonsdalia floriformis</i> var. (cf. <i>L. rugosa</i> ).		<i>Productus</i> 'giganteus.'

Mr. S. G. Perceval informs me that he has also found here:—

<i>Lithostrotion ensifer</i> ,		and
<i>Lithostrotion junceum</i> ,		<i>Cyathophyllum regium</i> .

The position of the beds is thus completely fixed in the *Lonsdalia*-Subzone.

- (6) Henbury Hill.

A little south of Blaize-Castle Wood, west of the Westbury and Henbury road, there is a quarry in Upper *Seminula*-Beds.

The usual fossils are found, and many of the beds are oolitic.

<sup>1</sup> These fossils are included, on the evidence of localized specimens in the Clifton-College Museum.

## (C) In the Wickwar-Sodbury Ridge.

## (1) The 'Wick Rocks,' and other exposures near Wick.

Wick lies on the east of the Bristol Coalfield,  $8\frac{1}{2}$  miles due east of the Clifton Suspension-Bridge. The Carboniferous projection at Wick is an inlier which marks the southern extension of the Wickwar-Sodbury ridge, below the capping of Mesozoic beds: it lies 6 miles due south of the end of that ridge at Sodbury. The general geology of the Wick district has been so thoroughly described by Prof. Lloyd Morgan<sup>1</sup> that any detailed account of the topography is rendered unnecessary.

## (a) The 'Wick Rocks' (including several quarries).

This is a fine section through the *Seminula*-Zone, from above  $S_1$  up to the concretionary beds at the top of the zone. So exactly does the palæontological sequence agree with that observed at Sodbury, that little more than a bare list of fossils will suffice:—

<i>Lithostrotion Martini</i> and variants.	<i>Productus</i> 'giganteus.'
<i>Syringopora</i> cf. <i>distans</i> and var.	<i>Chonetes</i> aff. <i>comoides</i> .
Clisiophyllid.	<i>Chonetes papilionacea</i> .
<i>Productus</i> aff. <i>Cora</i> .	<i>Seminula ficoidea</i> and allied forms.
<i>Productus</i> aff. <i>hemisphericus</i> .	

*Lithostrotion Martini* teems at the base.

*Productus* aff. *Cora*, in a characteristic form (mut.  $S_2$ ), occurs in the thick oolitic band.

*Seminula ficoidea* crowds certain beds in the upper part of the zone; and near the arch, where these beds are well weathered, specimens showing the spiral arms beautifully weathered out, are abundant. (Beds on the same horizon, just below the Observatory, on Observatory Hill, Avon section, exhibit the same character.)

*Chonetes papilionacea* crowds certain bands, which occur at intervals from the oolite onwards.

A Clisiophyllid is not common, but occurs occasionally from the oolitic band onwards.

These beds correspond exactly to those at Sodbury, east and west of Lilliput Bridge, and, in the Avon section, to the upper part of the Great Quarry.

## (b) The section at the Ochre Works.

*Lonsdalia*-Subzone (*Dibunophyllum*-Zone).

This section is almost identical with that at Wrington (see below, p. 242) and in Bridge-Valley Road, on the Clifton side of the Avon, as is shown by the following fossils:—

<i>Lithostrotion ensifer</i> .	<i>Lonsdalia floriformis</i> (and var. cf.
<i>Lithostrotion irregulare</i> .	<i>L. rugosa</i> ).
<i>Lithostrotion Portlocki</i> (var. <i>M'Coy-</i>	Konineckophyllid <i>Cyathophyllum</i> .
<i>anum</i> ).	<i>Dibunophyllum</i> $\psi$ .
	<i>Axophyllum</i> $\theta$ .

<sup>1</sup> Proc. Bristol Nat. Soc. n. s. vol. vi (1889-91) p. 183.

*Productus* aff. *scabriculus* (of two types: cf. *Pr. costatus* and *Pr. semireticulatus*).

*Spirifer* cf. *grandicostatus*.

*Spirifer* aff. *mosquensis*.

*Spirifer* cf. *ovalis*.

*Reticularia lineata* (cf. Dav. pl. xiii, fig. 10).

Note.—All the corals, with the exception of *Cyathophyllum*, are very abundant. *Productus* aff. *scabriculus* teems, the more finely-ribbed form being by far the most abundant. *Reticularia lineata* is a common fossil, but the *Spirifers* are rare.

### Horizon e.

Above the thickly-bedded limestones of the D<sub>2</sub> subzone occurs a series of thinly-bedded limestones, shales, and sandstones. The limestone-bands in this series are crowded with brachiopod-fragments.

<i>Productus</i> aff. <i>scabriculus</i> (cf. <i>P. costatus</i> )	} very common.
<i>Orthis crenistria</i> (mut.)	
<i>Chonetes</i> cf. <i>crassistria</i> .	
<i>Seminula</i> cf. <i>ficoidea</i> and <i>S.</i> cf. <i>ambigua</i> , less common.	

*Phillipsia*-fragments are of frequent occurrence.

Note.—The *Chonetes* is very similar to the form found in the Tournaisian, but its average dimensions are much smaller. On account of its small size, unbroken specimens are not unusual.

### (c) The lowest Millstone-Grit Quarry.

At the base of this quarry, immediately above the highest calcareous beds which are usually regarded as closing the Upper Limestone-Shales, is a sandstone crowded with casts of brachiopods, etc.

*Productus* aff. *scabriculus* is extremely abundant, and indicates Horizon e. This *Productus* is a different variant from that found in the Avon section; for, whereas the Avon form may be regarded as a scabriculate mutation of *Pr. costatus*, that at Wick is a scabriculate mutation of *Pr. semireticulatus*.

The chief interest of the Wick exposures centres in the fact that they complete the Sodbury section, by exhibiting the *Lonsdalia*-Subzone and Horizon e which are there absent.

### (2) Quarries at Wickwar, 4 miles north of Chipping Sodbury.

This district has already been described by Prof. Lloyd Morgan, in the British Association Handbook issued at the Bristol meeting in 1898.

### Detailed Account.

#### *Zaphrentis*-Zone.

##### *Resupinata*-subzone.

Lithological character.—Massive limestones.

Exposures.—Two adjacent quarries, immediately north of Wickwar, on the west side of the Charfield road.

#### Fauna:—

*Zaphrentis* aff. *Phillipsi*.  
*Zaphrentis* aff. *cornucopiae*.

*Michelinia* sp.  
*Syringopora* θ.

*Cliothyris glabristria*.  
*Cliothyris* sp. (transitional form).  
*Spirifer* aff. *clathratus* and var.  
*Syringothyris* aff. *cuspidata*.  
*Camarotoechia* aff. *mitchelleanensis*.  
*Orthotetes crenistria* (mut. Z).  
*Schizophoria resupinata*.

*Rhipidomella* aff. *Michelini*.  
*Leptena analoga*.  
*Productus* cf. *Martini*.  
*Productus* aff. *pustulosus*.  
*Productus* aff. *semireticulatus*.  
*Chonetes* cf. *hardrensis*.  
*Chonetes papilionacea*.

Notes.—*Spirifer* aff. *clathratus*, *Cliothyris glabristria*, and *Schizophoria resupinata* are commonest in the lower part of the subzone, but rare above. *Cliothyris glabristria* and *Schizophoria resupinata* are extremely abundant together. *Chonetes* cf. *hardrensis* teems in certain beds. *Chonetes papilionacea* only occurs abundantly in the upper part of the subzone.

*Euomphalus*, *Bellerophon*, and several very interesting bryozoans also occur.<sup>1</sup>

HORIZON  $\gamma$  is indistinguishable, since no specimen of *Caninia* was found above the *resupinata*-subzone and under the 'laminosa-dolomites.'

#### *Laminosa*-subzone.

Sequence in ascending order:—

- (1) 'Laminosa-dolomites.'
- (2) 'Caninia-Oolite' resting upon a highly-fossiliferous band (the 'sub-Oolite').

Exposures:—

- (1) can be seen at the top of the southernmost of the two quarries in the *resupinata*-beds.
- (2) is shown in a quarry a little farther west, and also in a very large disused quarry farther north, on the west of the Charfield road.

In both quarries the 'sub-Oolite' is well displayed.

Fauna:—

The 'laminosa-dolomites' are unfossiliferous, except for crinoid-fragments. The 'sub-Oolite' contains

<i>Caninia cylindrica</i> . <i>Syringothyris</i> aff. <i>laminosa</i> . <i>Seminula</i> sp. (very small form). <i>Rhipidomella</i> aff. <i>Michelini</i> .	$\left\{ \begin{array}{l} \textit{Orthotetes crenistria} \text{ (mut. C) and} \\ \textit{Chonetes aff. papilionacea} \end{array} \right\}$	in great abundance.
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*Orthotetes* is common in the base of the *Caninia*-Oolite.

#### *Seminula*-Zone (Upper $S_1$ and Lower $S_2$ ).

Lithological character.—Massive limestones, with shales, and a highly-quartzose grit.

Exposure.—A large quarry still farther west of the *resupinata*-quarries.

<sup>1</sup> *Palechinus* is common at this horizon throughout the Bristol area, a fact which was pointed out to me by Dr. Wheelton Hind (see also below, p. 256).

Fauna: <sup>1</sup>—

*Lithostrotion Martini* and vars.  
*Seminula ficoidea* and allied  
 forms.

*Productus*  $\theta$ .  
*Productus* aff. *hemisphericus*.  
*Productus* aff. *Cora* mut.

Comparison with other Sections.—So closely does the Wickwar development correspond to that in the Sodbury and Tytherington sections, that the enumeration of all the points of resemblance would be practically a repetition of the foregoing faunal lists. The most interesting points are:—

- (1) The absence of *Caninia* just above the *resupinata*-subzone, so that Horizon  $\gamma$  is not differentiated.
- (2) The occurrence of *Caninia* in the 'sub-Oolite,' as at Tytherington.
- (3) The early occurrence of an occasional *Seminula* in the sub-Oolite, as at Tytherington and Southmead.

## (D) In the Olveston-Tytherington-Cromhall Ridge.

This ridge forms the northern boundary of the Bristol Coalfield; it runs west-and-east, and is continuous with the north-and-south Wickwar-Sodbury-Ridge, which bounds the Coalfield on the east.

- (1) Old Down.—East of Olveston, about 9 miles north of Bristol, and 4 miles west of the Tytherington section.

Large quarries in the Upper *Seminula*-Zone.

## Fauna:—

<i>Lithostrotion Martini</i> (abundant).	<i>Seminula ficoidea</i> . <i>Productus</i> aff. <i>Cora</i> , mut. $S_2$ . }	} Abun- dant.
Clisiophyllids (occasional specimens of <i>Clisiophyllum</i> $\theta$ ).		

- (2) The Ridge Way.—There is a disused quarry, also in the Upper *Seminula*-Zone, at the junction of the road to New Passage with the Gloucester road, about  $1\frac{1}{2}$  miles north-east of Almondsbury.

## (3) Cromhall District.

(a) Ley-Hill Quarry.—A little more than half a mile north of Cromhall is a large road-metal quarry in the Upper *Zaphrentis*-Zone (*resupinata*-subzone), Horizon  $\gamma$ , and base of the *laminosa*-subzone.

<sup>1</sup> [As the result of a recent visit to this quarry, in the company of Dr. Wheelton Hind, I am enabled to add the following fossils to the above list:—

Upper  $S_1$ : *Productus semireticulatus* (mut.  $S_1$ ).

Lower  $S_2$ : *Productus fimbriatus* (only previously recorded in the south-west by Dr. W. B. Gubbin from South-Western Gower, where it occurs at the same level: Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. i, p. 45).

*Cyrtina carbonaria* (very abundant, and occurring at the same level as at Weston and Kidwelly: see below, p. 254).

Gasteropods belonging to several genera (*Bellerophon*, *Euomphalus*, *Loxonema*, etc.) are abundant (cf. Dr. Gubbin's paper, *op. cit.* pp. 46, 47).—A. V., April 26th. 1905.]

In the lower beds *Zaphrentis* aff. *cornucopiæ* is abundant, and fine specimens can be obtained. The uppermost beds show an unequalled development of the 'laminosa-dolomites.' *Chonetes* aff. *papilionacea* and *Orthotetes crenistria* mut. C occur in profusion.

(b) A limestone-quarry.—This quarry lies a short distance south-west of the last. It is mainly composed of an unfossiliferous limestone, which is perfectly white (the 'Caninia-Oolite'). At the base are the uppermost beds of the 'laminosa-dolomite,' teeming with *Chonetes* aff. *papilionacea* and *Orthotetes crenistria*.

(c) 'Near' Cromhall.—In Mr. Champion's Collection there are specimens of *Lithostrotion Martini*, which certainly indicate the *Seminula*-Zone.

I have no doubt that a very complete section could be constructed, from all the exposures between Cromhall and Charfield; the exact resemblance of those exposures which I have examined, to those already described in other parts of the Bristol area, suggests, however, that the results would present no special interest.

### (E) The Backwell-Wrington Mass.

This triangular mass of Carboniferous Limestone, which measures  $5\frac{1}{2}$  miles from west to east and  $3\frac{1}{4}$  miles from north to south, lies south-west of Bristol and due west of Dundry Hill.

The general structure of the mass is an anticline, the crest of which runs west-and-east, a little south of Broadfield Farm, thus dividing the mass into two very unequal parts, namely, a broad northern part and a much narrower southern part. The crest of the anticline had been eroded in post-Carboniferous times and is now partly concealed, immediately south of Broadfield Farm, beneath Rhætic and Liassic deposits.

### Detailed Account.

#### Upper Tournaisian.

*Resupinata*-subzone (including Horizon  $\gamma$ ).

Exposures.—Along the crest of the anticline and, underlying the lavas of Goblin Combe, on both sides of the anticline.<sup>1</sup>

Fauna:—

*Zaphrentis* aff. *Phillipsi*.  
*Zaphrentis* aff. *cornucopiæ*.  
*Caninia cylindrica*.  
*Amplexus* cf. *coralloides*.

*Spirifer* aff. *clathratus*.  
*Syringothyris* aff. *laminosa*.  
*Cliothyris* sp.

The only point that is worth emphasizing is the strong definition of Horizon  $\gamma$ , a fact which indicates our approach towards the Mendip area, where *Caninia* and *Amplexus* occur abundantly.

<sup>1</sup> C. Lloyd Morgan & S. H. Reynolds, Quart. Journ. Geol. Soc. vol. 1x (1904) p. 137.



*Laminosa*-subzone.

Exposure and fauna.—This subzone is represented by beds, above the lavas, on both sides of the anticline, which contain *Orthotetes crenistria* and *Chonetes* aff. *papilionacea*, as well as *Ch.* cf. *comoides*, in extreme abundance. An occasional specimen of *Syringothyris* aff. *laminosa* is found, associated with the fossils just mentioned.

These beds are, in all probability, the equivalent of the ‘sub-Oolite.’

## Viséan.

*Seminula*-Zone.

The whole or part of the series, from the top of  $S_1$  up to the top of the zone (that is, up to the concretionary beds or ‘mottled limestones’), is well exposed at several points.

## Exposures:—

- (1) Dod’s Quarry on the north-eastern edge of the mass, about 1 mile west of Dundry Hill, and three quarters of a mile south of Barrow Gurney.<sup>1</sup>
- (2) Backwell Quarry, on the northern edge of the mass, nearly  $2\frac{1}{2}$  miles west of Barrow Gurney.
- (3) A quarry on the southern edge of the mass, about 1 mile west of Wrington, on the north side of the Yatton-Wrington road.
- (4) At Cleve, near the entrance to the Combe.
- (5) Near Yatton, in the small separated mass which lies off the south-western corner of the Backwell-Wrington mass.

Since the beds exposed in (2), (3), (4), and (5) are smaller portions of the series, which are included in the longer sequence represented in (1), and since they have no lithological or palæontological peculiarities, it will suffice to enumerate the palæontological characters exhibited by exposure (1).

Lithological character.—Massive limestones, with a thick band of oolite, and, at the top, ‘mottled limestones’ with thin shales.

## Fauna:—

? *Caninia cylindrica* mut.

*Lithostrotion Martini*.

*Syringopora* cf. *distans*.

*Syringopora* cf. *ramulosa*.

A Clisiophyllid (rare).

*Seminula ficoidea* and allied forms.

*Orthotetes crenistria* mut.  $S_1$  (occasional).

*Productus* aff. *Cora*.

*Productus* ‘*giganteus*.’

*Productus* sp. (cf. *Pr.*  $\theta$ ).

*Chonetes* cf. *comoides*.

*Chonetes papilionacea*.

The faunal sequence and the lithological details are so remarkably similar to those of the beds in the Wick-Rock Series already described (p. 236), that no further comment is necessary.

<sup>1</sup> Barrow Gurney lies about  $4\frac{1}{2}$  miles south-west of the Clifton Suspension-Bridge.

*Dibunophyllum*-Zone.

(a) The lower part or  $\theta\phi$ -subzone is, so far as I know, unexposed.

(b) The upper part or *Lonsdalia*-Subzone.

Exposure.—In the large quarry now worked, on the southern edge of the mass, immediately north of Wrington.

Lithological character.—Massive limestones with some shales, and rubbly limestones.

## Fauna:—

*Alveolites septosa*.

*Syringopora* cf. *distans*.

*Lithostrotion ensifer*.

*Lithostrotion Martini* and especially a mutation towards *L. irregulare*.

*Lithostrotion Portlocki* and var.

*M. Cayanum*.

*Cyathophyllum regium* (simple and compound).

*Cyathophyllum Murchisoni* (var.).

*Lonsdalia floriformis* and the var. cf. *rugosa*.

Clisiophyllids of three main types, namely: *Dibunophyllum*  $\psi$ , *Axophyllum*  $\theta$ , and *Koninckophyllum*  $\phi$ .  
*Seminula* aff. *ficoidea* (scarce).

*Spirifer* cf. *grandicostatus* (cf. Davidson, 'Monogr. Brit. Palæoz. Brachiop.' Palæontogr. Soc. pl. vii, fig. 8).

*Spiriferina* (?) cf. *integricosta* (cf. Davison, pl. ix, fig. 16).

*Reticularia lineata*.

*Camarotoechia pleurodon* (cf. Davidson, pl. xxiii, fig. 2).

*Productus* aff. *Cora* (mut.).

*Productus hemisphericus*.

*Chonetes* sp.

*Aviculopecten* sp.

Fenestellids.

*Fistulipora* (?).

Notes.—The Wrington quarry is now the best exposure in the Bristol area, from which to collect the corals of this subzone. The coral-fauna is identically that of the same horizon in the Avon section, as exhibited in the exposures on the river-side of Stokeleigh Camp, in the quarry on Rowanham Hill, and at Round Point on the Clifton side of the river.

The brachiopods and lamellibranchs occur crushed in a thin shale, consequently their determination is a matter of considerable difficulty and uncertainty.

A curious form of Fenestellid is met with, both at Wrington and at Round Point.

I have now completed the detailed account of the several zones, as they are displayed in the different parts of the Bristol area. Before proceeding to compare the zonal sequence in the Bristol area with that in other districts, it will be necessary to compile a table of the commonest corals and brachiopods, which shall show the range and maximum of each species-group (or gens) throughout the zonal sequence adopted in this paper for the Bristol area. By comparing this table with similar tables for distant areas, it will be possible to plot accurately the directions and amount of the great geographical variations in relative sequence, which the different species-groups undergo.

The smaller variations, which take place within the Bristol area itself, have been noticed here and there in the detailed description of the different parts of that area, and the importance of such observations, when completed, has been pointed out in the Introduction (p. 185).

The table and the range-diagrams (which express the same results graphically) are compiled for the Bristol area as a whole, and from the data supplied by that area alone: that is, no account is taken, either of any district outside the Bristol area, or of the smaller variations within the area itself.

### III. RANGES AND MAXIMA OF THE CORALS AND BRACHIOPODS IN THE BRISTOL AREA. (Pls. XXVIII & XXIX.)

#### CORALS.

##### Alveolites.

Species-group: *Alveolites septosa*.

Very rare at the top of  $S_1$ ; commoner in  $S_2$ ; abundant throughout D; maximum in  $D_1$ .

##### Syringopora.

Genus: rare in  $Z_1$ ; abundant at numerous levels throughout all the higher zones.

Circuli:—

- (1) *Syringopora*  $\theta$ :  $Z$ ; maximum in  $Z_2$  and  $\gamma$ .
- (2) *S. cf. distans*: common throughout S and D.
- (3) *S. cf. ramulosa*: not uncommon in S.
- (4) *S. cf. geniculata*: maximum in  $D_1$ .
- (5) *S. cf. reticulata*: maximum in  $C_1$ .

##### Michelinia.

Genus: rare in  $Z_1$ ; maximum at the top of  $Z_2$  and in C.

Species-groups (?): not satisfactorily differentiated.

The form in  $Z_1$  is *Michelinia cf. favosa*; the commonest form in  $Z_2$  and C is *M. megastoma*.

##### Cleistopora.

Species-group: *Cleistopora aff. geometrica*.

Confined to K; maximum at the top of  $K_2$ .

##### Zaphrentis.

Species-groups:—

- (1) *Zaphrentis aff. Phillipsi*. Not infrequent in  $Z_1$ ; extremely abundant in  $Z_2$  and  $\gamma$ ; rare in C.
- (2) *Zaphrentis aff. cornucopiae*.  $Z_2$  and  $\gamma$  (abundant); maximum at the top of  $Z_2$ ; rare in  $C_1$ .

##### Caninia.

Species-group: *Caninia cylindrica*.

Occasional at the top of  $Z_2$ ; maximum in  $\gamma$ ; rare in C; 2nd maximum in  $S_1$ .

Mutational stages:—

- (a) *Caninia cylindrica*:  $\gamma$  and C.
- (b) *Caninia cylindrica* var. *bristolensis*: C and  $S_1$ .

##### Amplexus.

Species-group: *Amplexus cf. coralloides*.

$Z_2$ ,  $\gamma$ , C, and probably  $S_1$ ; maximum near the top of  $Z_2$ .

**Lithostrotion.**(A) The *Siphonodendron*-Section.

## Species-groups:—

- (1) *Lithostrotion Martini*. Abundant from the middle of  $S_1$ ; throughout all higher zones; maximum in  $S$ .

## Mutations:—

Towards *Lithostrotion irregulare*:  $D$  (common).

„ *Lithostrotion affine*:  $S_2$  and  $D$ .

„ *Lonsdalia*:  $D_2$  (common).

- (2) *Lithostrotion irregulare* (doubtfully a distinct species-group). Abundant throughout  $D$ ; maximum in  $D_2$ .

- (3) *Lithostrotion junceum*. Never abundant, but not uncommon at certain levels in  $D$ .

(B) The *Nematophyllum*-Section.

## Species-groups:—

- (4) *L. basaltiforme*: upper part of  $S_1$  and lower part of  $S_2$ .

- (5) *L. Portlocki* (including the variants *L. McCoyanum* and *L. ensifer*).  $D_2$  (abundant).

**Cyathophyllum.**

## Species-groups:—

- (1) *Cyathophyllum Murchisoni*-group.

## Mutational stages:—

(a) *Cyathophyllum*  $\phi$ :  $C$  (maximum at the top).

(b) *Cyathophyllum Murchisoni* (s. s.): rare in  $S_2$ ; abundant in  $D$ ; a maximum in  $D_1$ .

- (2) *Cyathophyllum regium*.  $D_2$  (abundant).

- (3) *Koninckophyllid Cyathophyllum*.  $D$ ; maximum in  $D_1$ .

**Campophyllum.**

Species-group: *Campophyllum Murchisoni*.  $D$ ; maximum in  $D_1$ .

**Clisiophyllids.**

Not uncommon in  $S_2$ ; maximum in  $D$ .

- (i) *Clisiophyllum*. (*Carcinophyllum*.)

Species-group: *Clisiophyllum*  $\theta$ .  $S_2$ ;  $D_1$  (maximum).

- (ii) *Dibunophyllum*.

Species-group: *Dibunophyllum turbinatum*.

## Mutational stages:—

(a) *Dibunophyllum*  $\theta$  and *Dib.*  $\phi$ :  $S_2$  (rare);  $D_1$  (maximum).

(b) *Dibunophyllum*  $\psi$ :  $D_1$  (?);  $D_2$  (maximum).

- (iii) *Cyclophyllum*:  $D_1$  (rare locally).

- (iv) *Koninckophyllum*:  $D$  (common locally).

- (v) *Axophyllum*:  $D_2$  (common).

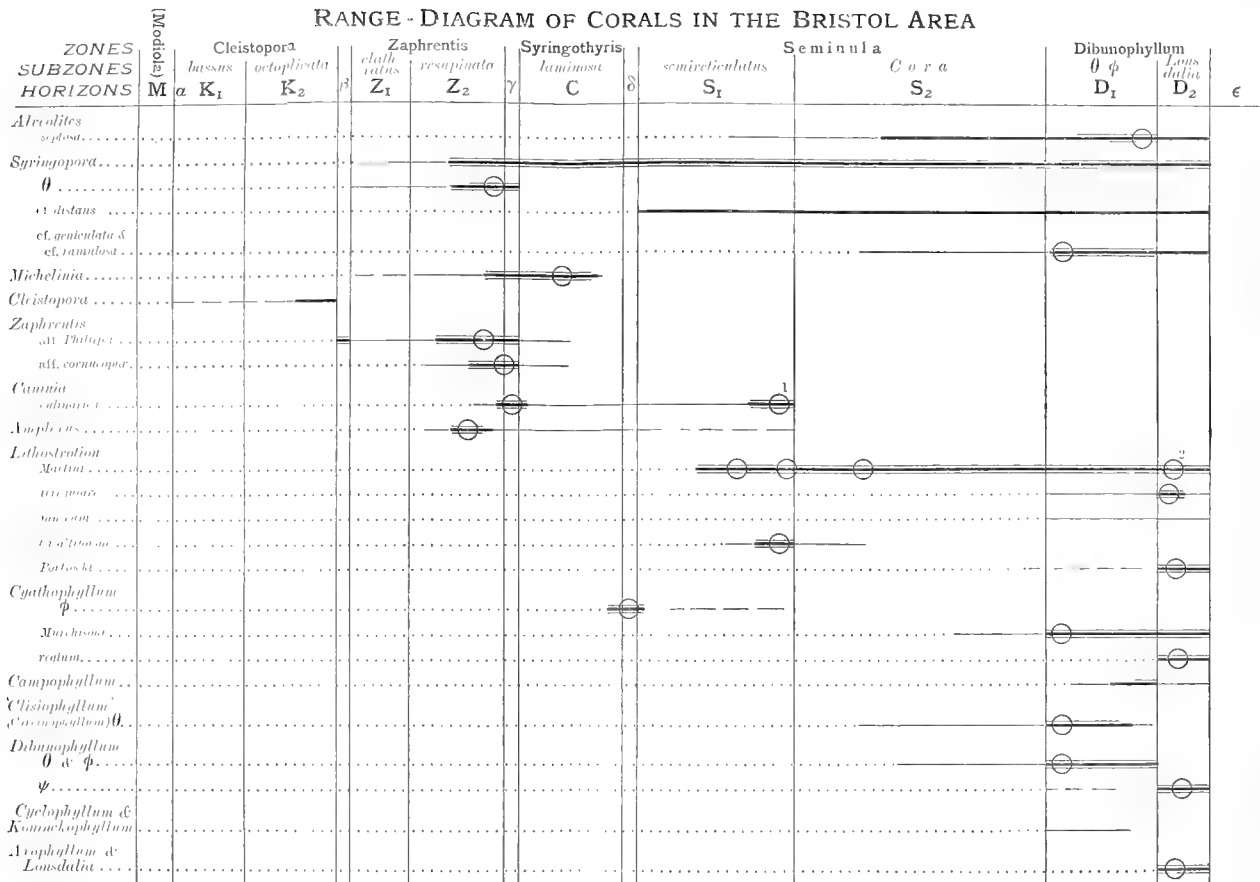
- (vi) *Lonsdalia*.

Species-group: *Lonsdalia floriformis* (including var. *L. cf. rugosa*).  $D_2$  (very abundant).

aa. Thick continuous lines indicate common occurrence.  
Two or three parallel lines indicate abundance.



## RANGE-DIAGRAM OF CORALS IN THE BRISTOL AREA



## Notes:-

1. *Caninia cylindrica* var. *bristolensis*.
2. Maximum of the mutation with *Chisophyllid* affinity.

The circles indicate approximate positions of maxima.  
Thin continuous lines indicate rarity.

Thick continuous lines indicate common occurrence.  
Two or three parallel lines indicate abundance.





## BRACHIOPODS.

## Athyrids.

(i) *Cliothyris*.

Species-groups:—

- (1) *Cliothyris Royssii*. The typical form is abundant in M and K<sub>1</sub>.

A mutation (mut.  $\beta$ ) is abundant in K<sub>2</sub>; it reaches a maximum at  $\beta$ , and is not uncommon in Z<sub>1</sub>.

- (2) *Cliothyris glabristria*. Rare in K; abundant throughout Z; maximum in the lower part of Z<sub>2</sub>.

- (3) *Cliothyris* sp. (a transitional form between *Cliothyris* and *Seminula*). Top of Z<sub>2</sub> and C; maximum near  $\gamma$ .

(ii) *Seminula*.

Species-group: *Seminula ficoidea*. Rare in C; prolific throughout S; scarce in D.

## Spiriferids.

(i) *Reticularia*.

Species-group: *Reticularia* aff. *lineata*. Rare in K; abundant in Z (maximum in Z<sub>1</sub>); a mutation in C and S; a well-defined mutation in D<sub>2</sub> (*Reticularia lineata*).

(ii) *Spirifer*.

Species-groups:—

- (1) *Spirifer tornacensis*, represented by *Sp.* aff. *clathratus* and its variety, and by *Sp.* aff. *cinctus*. Rare in K<sub>1</sub>; increasing in abundance in K<sub>2</sub>; prolific in  $\beta$  and Z<sub>1</sub>; declining in Z<sub>2</sub>; very rare after  $\gamma$ .

- (2) *Spirifer mosquensis*, represented by a local variation. Rare in D<sub>2</sub>.

(iii) *Spiriferina*.

Species-group: *Spiriferina octoplicata*. Rare in K<sub>1</sub>; abundant in K<sub>2</sub> and at  $\beta$ ; scarce in Z<sub>1</sub>.

(iv) *Syringothyris*.

Species-groups:—

- (1) *Syringothyris cuspidata*.

Mutational stages:—

- (a) *Syringothyris* aff. *cuspidata* (cf. *S. subcuspidata*) (probably more than one stage is here represented). Probably occurs in M; abundant from the top of K<sub>1</sub> to  $\beta$ , and extends into Z.

- (b) *Syringothyris cuspidata* (the typical form). Occurs in Z<sub>1</sub>; prolific at the top of Z<sub>2</sub> and at  $\gamma$ ; not uncommon throughout C.

- (2) *Syringothyris* aff. *laminosa*.

Common in Z<sub>3</sub>,  $\gamma$ , and C; a mutation occurs in S<sub>1</sub>; maximum in Z<sub>2</sub>.

**Retzids.**

*Eumetria*: M and K<sub>1</sub>.<sup>1</sup>

**Rhynchonellids.**

*Camarotæchia*.

Species-group: *Camarotæchia mitcheldeanensis* (including two or more mutational stages). Abundant in M, K, and Z<sub>1</sub>; rare in Z<sub>2</sub>; very scarce in C.

**Orthids.**

(i) *Schizophoria*.

Species-group: *Schizophoria resupinata*. Very rare in Z<sub>1</sub>; abundant in the lower part of Z<sub>2</sub>; rare in γ.

(ii) *Rhipidomella*.

Species-group: *Rhipidomella* aff. *Michelini*. Rare in K<sub>2</sub>; abundant in Z (maximum probably at the top of Z<sub>1</sub>); rare in C.

**Strophomenids.**

(i) *Orthotetes*.

Species-group: *Orthotetes crenistria*.

This group persists throughout the whole of the Carboniferous Limestone; but, whereas it is extremely abundant all through the Tournaisian, it becomes comparatively unimportant in the Viséan.

The group undergoes well-marked mutational change, and the following stages in mutation can be easily distinguished:—

Mut. K<sub>1</sub>: maximum in K<sub>1</sub>; extends into K<sub>2</sub>.

Mut. Z: K<sub>2</sub>, Z, and C.

Mut. C: Z<sub>2</sub>, γ, and C.

Mut. S: S (chiefly S<sub>1</sub>).

Mut. D<sub>1</sub>: S<sub>2</sub> and D<sub>1</sub>.

(ii) *Leptena*.

Species-group: *Leptena analoga*. Occurs in α; abundant in K and Z; unknown in C.

**Productids.**

(Very much more work must be done, both in the field and in the laboratory, before the true inter-relationship of the several members of this family and their ranges in time can be considered as satisfactorily established in the Bristol area.)

(i) *Productus*.

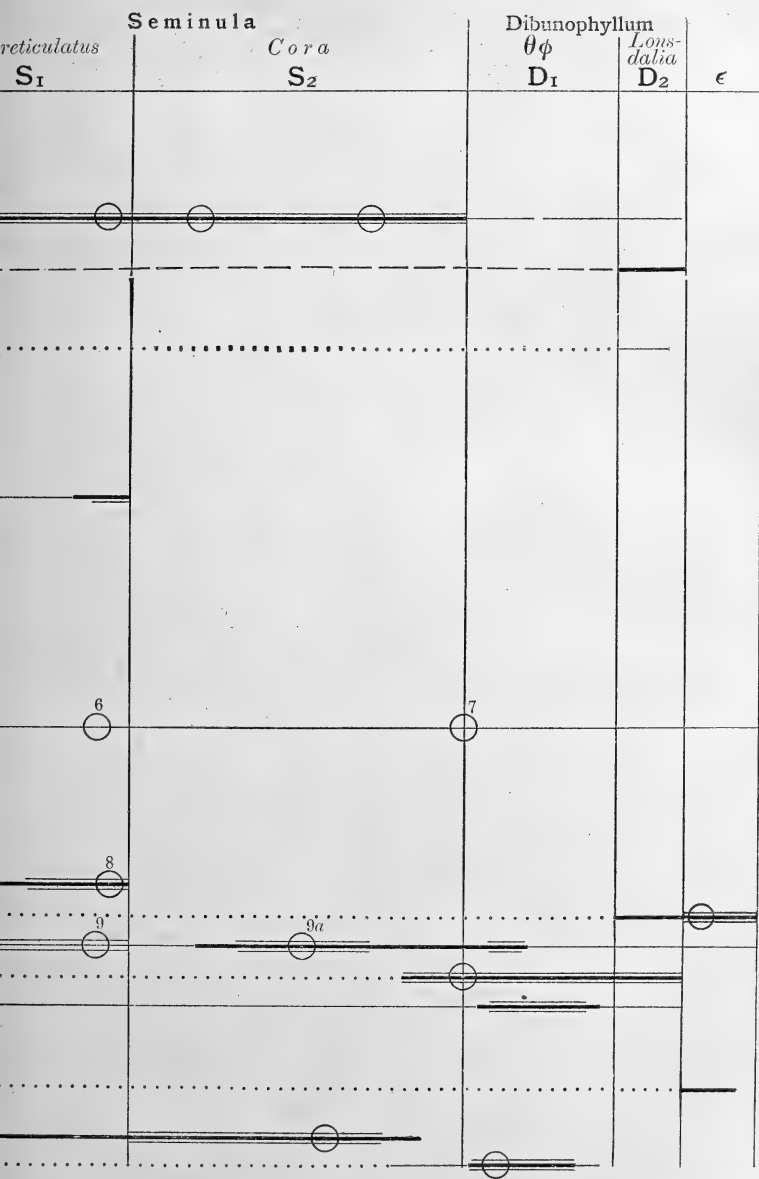
Species-groups:—

(1) *Productus bassus*. Very abundant in K<sub>1</sub>; doubtfully recorded from K<sub>2</sub>.

(2) *Productus* cf. *Martini* (including variations towards *Pr. longispinus* and *Pr. semireticulatus*). Abundant in

<sup>1</sup> A single specimen has been discovered near the top of K, in the Failand section.

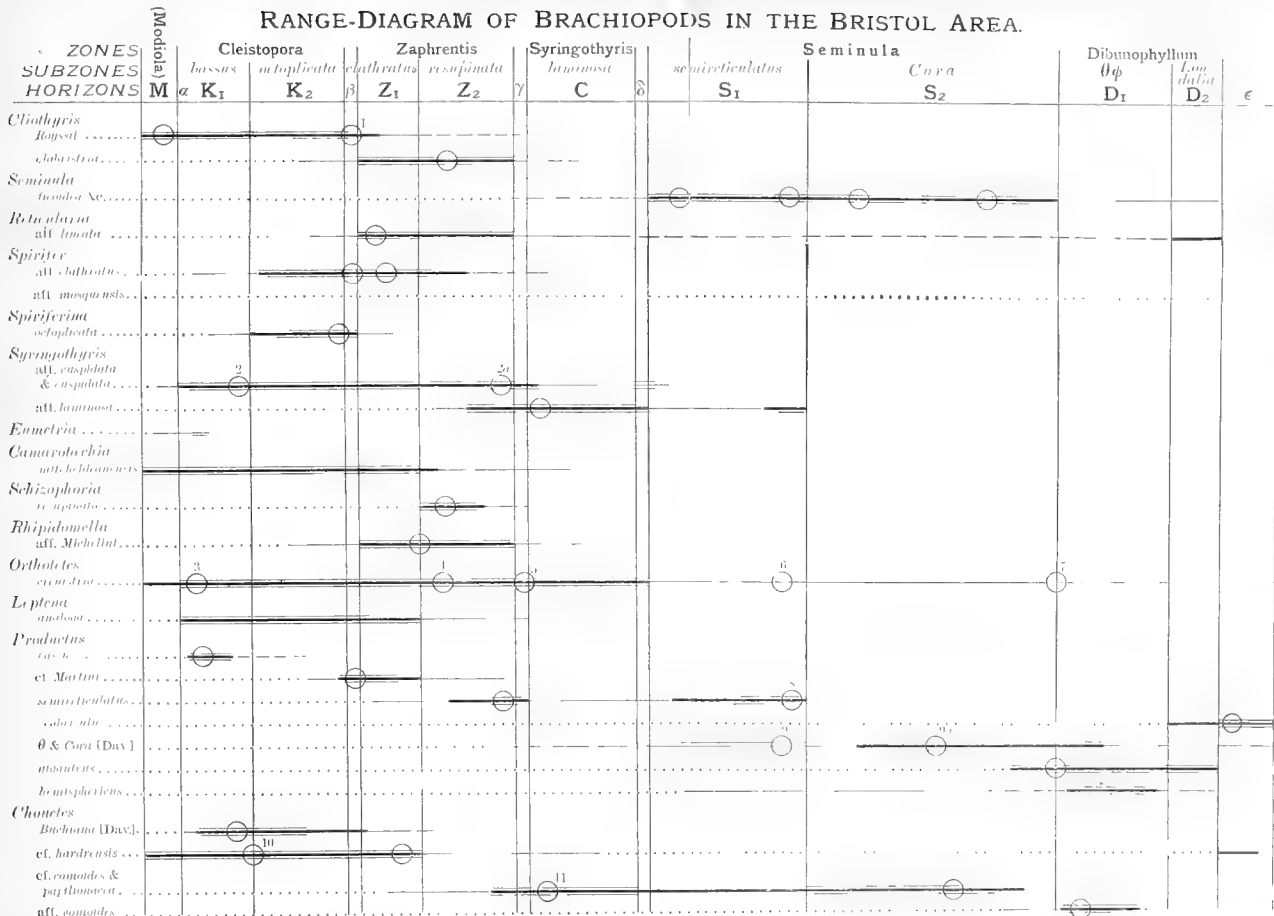
# S IN THE BRISTOL AREA.



*Orthotetes crenistria* mut. *S*.  
 " " mut. *D<sub>1</sub>*.  
*Productus semireticulatus* mut. *S<sub>1</sub>* (spinous form)  
*Productus*  $\theta$ . 9a. *Prod. Cora* [Dav] mut. *S<sub>2</sub>*.  
 Tax. of coarse-ribbed form (*Chonetes* cf. *crassistria*)  
*Chonetes* cf. *comoides* and early *Papilionaceans*.  
 see the diagram of Corals.



## RANGE-DIAGRAM OF BRACHIOPODS IN THE BRISTOL AREA.



Notes:- 1. *Cleiothyris Roysii* mut. β  
 2. *Syringothyris* aff. *cuspidata*.  
 2a Typical large form of *Syr. cuspidata*.  
 3. *Orthotetes crenistris* mut. K<sub>1</sub>.  
 4. " " mut. Z<sub>1</sub>.  
 5. " " mut. C.  
 6. " " mut. C.

6. *Orthotetes crenistris* mut. S.  
 7. " " mut. D<sub>1</sub>.  
 8. *Productus semitruncatus* mut. S<sub>2</sub> (spinose form)  
 9. *Productus* θ. or *Prod. Cora* (Dax) mut. S<sub>2</sub>.  
 10. Max. of near-c ribbed form (*Chonetes* cf. *crassistris*)  
 11. *Chonetes* cf. *comoides* and early *Pythomacra*

For the explanation of the conventional signs see the diagram of Corals.



- $K_2$ ,  $\beta$ ,  $Z_1$ ; the typical form is rare in  $Z_2$ , where it is replaced by a mutation towards *Pr. semireticulatus*.
- (3) *Productus semireticulatus*. The mutation from *Pr. Martini* occurs in  $Z_1$ , and becomes abundant in  $Z_2$ . A spinous mutation is characteristic of  $S_1$ .
- (4) *Productus* aff. *scabriculus* (including two distinct variations; the one *Pr. cf. costatus*, the other *Pr. cf. semireticulatus*). Typical of Horizon  $\epsilon$ ; less common in  $D_2$ .
- (i A) The Giganteid *Producti* (a group having subgeneric value).
- (5) *Productus* aff. *Cora* [Dav.] (= *Pr. corrugatus*). Rare in  $Z$  and  $C$ ; abundant in  $S_2$ ; common in  $D_1$  and extending on to Horizon  $\epsilon$ .
- The different zones are characterized by distinct mutations (thus mut.  $Z$ , mut.  $C$ , mut.  $S_2$ , and mut.  $D_1$  are easily distinguished).
- Productus*  $\theta$  is abundant in  $S_1$ .
- (6) *Productus giganteus*. Rare at the bottom of  $S_2$ ; maximum at the top of  $S_2$  and the bottom of  $D_1$ ; extends on into  $D_2$  in a distinct mutation ('*Chonetiproductus*').
- (7) *Productus hemisphericus*. The typical form is only abundant at the top of  $S_2$  and in  $D_1$ .

(ii) *Chonetes*.

Species-groups:—

- (1) *Chonetes* '*Buchiana*'<sup>1</sup> (as figured by Davidson, 'Monogr. Brit. Palæoz. Brachiop.' Palæontogr. Soc. pl. lv, fig. 12) has its maximum at the top of  $K_1$ .
- (2) *Chonetes* cf. *hardrensis*:  $K$ ;  $Z$ ;  $C_1$ .

Variants:—

- (a) *Chonetes* cf. *crassistria*. Rare in  $M$ ; very abundant in  $K$ ; extends into  $Z_1$ . A somewhat similar form reappears in  $\epsilon$ .
- (b) *Chonetes* cf. *laquessiana*.  $K$  and  $Z$ .
- (3) *Chonetes papilionacea*. Rare in  $Z_1$ ; common in  $Z_2$ ; abundant at  $\gamma$ , in  $C$ , and at intervals throughout  $S$ .

Variants:—

- (a) *Chonetes* cf. *comoides* is locally abundant in  $C$ .
- (b) *Chonetes* aff. *comoides* is characteristic of  $D_1$ .

## Inarticulate Brachiopods.

### *Lingula* and (*Discina*).

Paucity of material has prevented any attempt to separate the forms which occur at different levels.

<sup>1</sup> I am not satisfied that this form is correctly referred to *Chonetes Buchiana*, de Kon.

#### IV. COMPARISON OF THE BRISTOL SEQUENCE WITH THAT IN NEIGHBOURING AREAS.

My only object in this section is to demonstrate that the progression of zonal faunas, which has been established for the Bristol area alone, holds true throughout the South-West of England and South Wales.

Since each area to which I shall refer is now undergoing detailed examination, it would be premature, as well as out of place, to attempt here anything beyond a statement of the broad outlines of the faunal succession. The lithological development will be entirely passed over, except in so far as the occurrence of dolomites or grits may interrupt the faunal sequence.

##### (i) THE MENDIP AREA.

The brief account which follows is mainly compiled from an examination of the following localities:—

##### (a) Burrington Combe.<sup>1</sup>

Zonal extent: All the zones and subzones are here excellently exposed and typically developed, from M up to and including D<sub>1</sub>.

##### (b) Traverse from Cheddar to Charterhouse.

Zonal extent: Same as at Burrington, but the sequence is not completely exposed. The Cheddar Gorge displays the *Seminula*-Zone ending in D<sub>1</sub>; there are numerous exposures in the *Zaphrentis*-Zone (both Z<sub>1</sub> and Z<sub>2</sub>) between the Gorge and Charterhouse.

##### (c) Emborough.

Specimens collected by Prof. S. H. Reynolds and Mr. T. F. Sibly point clearly to the presence of a normal D<sub>2</sub> facies in the Mendip development.<sup>2</sup>

Interruptions of faunal sequence by dolomites or grits: practically none. Hence the prolific fauna of the *Syringothyris*- and lowest *Seminula*-Beds is in striking contrast to its rarity in the Bristol area.

#### Correlation of the Mendip and Bristol Areas.

So closely does the faunal sequence in the two areas agree, that it is only by dint of detailed study that the small differences become apparent.

The following points of resemblance, selected from a very long list, will serve to give an idea of the practical identity of the

<sup>1</sup> This section has been more recently examined in great detail by Mr. T. F. Sibly, and his results are published in the *Proceedings of the Bristol Naturalists' Society*, ser. 4, vol. i, pt. i, p. 14.

<sup>2</sup> The detailed examination of the Carboniferous Limestone throughout the Mendip area is being undertaken by Mr. T. F. Sibly, and to him I am indebted for several of the facts stated below.



sequence in the two areas. All the statements refer equally to either area.

1. The Carboniferous Limestone starts with a *Modiola*-ostracod phase, which includes an identical horizon (Horizon  $\alpha$ ).
2. The *Cleistopora*-Zone can be differentiated into two subzones  $K_1$  and  $K_2$ , characterized by the same faunal assemblages in the two areas. Striking constituents, such as *Productus bassus* and *Chonetes* '*Buchiana*,' occur in both areas. The period of entrance, the gradual increase in numbers, and the position of maximum in the case of the commonest constituents is the same (for example, *Spirifer* aff. *clathratus*).
3. The same species, in identical forms, are associated in  $Z_1$ , and the forms decline in numbers when traced through  $Z_2$ .
4. *Amplexus* attains its maximum before *Caninia* in  $Z_2$ .
5. *Zaphrentis* is common throughout the *Zaphrentis*-Zone, but is rare in all higher beds. It attains its maximum at the top of  $Z_2$ , where it is represented by the two common species. In  $Z_1$ , *Zaphrentis* aff. *Phillipsi* is the only form met with.
6. *Schizophoria resupinata* is associated with *Cliothyris glabristria*.
7. *Caninia* is enormously abundant at the top of the *Zaphrentis*-Zone and extends on into C.
8. *Michelinia* has its maximum in Z (*fide* T. F. S. for Burrington).
9. *Orthotetes crenistria* is quite common throughout the Tournaisian, but is rare above that level, although occasionally found up to the *Dibunophyllum*-Zone.
10. *Chonetes* cf. *hardrensis* occurs abundantly up to the top of  $Z_2$ , but yields its predominance in higher beds to *Chonetes papilionacea*, by which it is soon entirely replaced.
11. At the base of C there is a band crowded with *Orthotetes crenistria* and *Chonetes* cf. *comoides* in association.
12. *Cyathophyllum*  $\phi$  is enormously abundant at the top of C, associated with *Bellerophon* sp., *Orthotetes crenistria*, and *Syringothyris* aff. *laminosa*.
13. *Productus*  $\theta$  is extremely prolific at the bottom of the *Seminula*-Zone (where, however, *Lithostrotion* and *Seminula* are rare at Burrington).
14. *Lithostrotion Martini* abounds in the middle of the *Seminula*-Zone, where it is associated with *Productus* and *Seminula*.
15. Clisiophyllids enter in small numbers in the upper part of the *Seminula*-Zone.
16. The fauna of the *Dibunophyllum*-Zone is identical in the two areas.

The points of difference, though small, are of great interest; they may be summed up in the statement that, when compared with the Bristol area, the coral-fauna in the Tournaisian of the Mendips is accelerated relatively to the brachiopod-progression.

(1) In the Mendip development *Michelinia* occurs commonly with the assemblage of brachiopods characteristic of  $Z_1$ , whereas in the

Bristol area the genus is extremely rare before  $Z_2$ ; *Zaphrentis* is also much more abundant in  $Z_1$  than it is in the Bristol area.

(2) The most conspicuous instance of this small relative displacement of corals and brachiopods is, however, to be seen in the range of *Caninia cylindrica* in the two areas. In the Bristol area the maximum of *Caninia* occurs above the brachiopod-facies which is typical of  $Z_2$ , and the maximum of *Syringothyris cuspidata* occurs just below that of *Caninia*. In the Mendip area, however, the maximum of *Caninia* is associated with a typical  $Z_2$  facies of brachiopods, and the maximum of *Syringothyris cuspidata* occurs above that of *Caninia*.

The brachiopod-progression is identical in both areas, as is also the coral-progression; but the one is slightly displaced relatively to the other, as we pass from the Mendip area into the Bristol area. The same phenomenon is exhibited in the position of the second maximum of *Caninia*; in the Mendips it takes place at the top of C, in the Bristol area it occurs in  $S_1$ .

The remaining areas will, for want of space, be treated very shortly, and the statement that a certain zone or subzone is present must be taken to imply that the assemblage of fossils by which it is characterized in the Bristol area occurs also in the area under consideration.

#### (ii) THE WESTON AREA.

1. The Woodspring ridge exhibits a very fossiliferous development of  $Z_2$ , succeeded by characteristic 'laminosa-dolomites' and 'Caninia-Oolite.' There is practically no difference between the fauna here and in the Clevedon area.

2. The west of the Worle ridge from Spring Cove to Knightstone.

The upper part of C and the Viséan, up to a high level in  $S_2$ , are quite characteristically displayed. The upper part of C is little dolomitized, so that it exhibits the fossiliferous character which it has in the Mendips.

Note.—From material supplied to me by Prof. C. Lloyd Morgan & Prof. S. H. Reynolds when they were preparing their paper,<sup>1</sup> I came to the conclusion that both the lava at Woodspring and that at Spring Cove were poured out at approximately the same epoch; and, speaking broadly, this has been confirmed by more careful examination in the field. Both flows certainly took place during the deposition of the *laminosa*-subzone. Having, however, examined the beds *in situ*, I am now able to fix accurately the time of each flow: that at Woodspring occurred in  $\gamma$ , that is, at the very beginning of *laminosa*-time in the Weston area, whereas that at Spring Cove occurred later, but still before the close of the *laminosa*-age.

The evidence for this conclusion is definite: at Spring Cove *Cyathophyllum*  $\phi$  occurs below the lava, thus placing the volcanic rocks in the upper part of the *laminosa*-subzone, whereas at Woodspring the lava occurs at the  $\gamma$  horizon.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lx (1904) p. 151.

I have hastened to make this correction, for the assistance of those who are working in neighbouring areas, in the hope that, the horizons of the two flows being now very definitely fixed, they may find some trace of volcanic ejectamenta at the same levels.

I am deeply indebted to Mr. Sibly, who has placed his knowledge of the area and its fossils entirely at my service, and it was under his guidance that I first visited the Woodspring-Cliff section.

### (iii) THE CHEPSTOW AND FOREST-OF-DEAN OUTCROP.

Although I have not yet completed the examination of this large area, the agreement of the faunal succession with that in the Bristol area is practically complete whenever palæontological evidence can be found. A great portion of the faunal sequence is, however, entirely obscured by the extensive development of dolomites in the Upper Tournaisian and by the early entrance of the 'Millstone-Grit' facies before the end of Viséan time.

It will be sufficient, for my present purpose, to describe briefly the development in the south and in the extreme north-east of the area.

#### A. The Chepstow Area (including Chepstow near its north-eastern corner and Magor at the extreme south-west).

1. The Lower *Cleistopora*-Zone contains the typical  $K_1$  fauna; immediately following upon a series of transitional beds in which fossils are extremely scarce.

2. The base of  $Z_1$  is represented by the characteristic forms, in their usual abundance.

3. For some distance above this level the beds are extensively dolomitized, and fossils are consequently rare.

4. There is, however, a well-marked fossiliferous band, which extends throughout the district, and contains a typical assemblage of  $Z_2$  forms.

5. For some distance above this level there is a great lack of exposures, and the next higher beds which are met with belong to the *Seminula*-Zone.

6. As in the Bristol area, this zone is thick; it contains the typical assemblage of fossils. The *Seminula*-Zone is splendidly displayed in the large quarries on the left bank of the Wye, immediately north of Chepstow.

7. I have seen no trace of the *Dibunophyllum*-Zone.

#### B. The Mitcheldean District.

The main interest of this region, which I have recently examined with great care, lies in the interpretation of the rock-facies rather than in the faunal sequence. The faunal succession is quite normal, and the different fossiliferous levels can be assigned to their correct horizons without any difficulty or question. All the fossils that

occur are found also in the Bristol area, and they are associated in the same way in the two areas.

Briefly stated, the succession is as follows :—

1. A series of transitional beds containing few fossils, the same early representatives of a *Cleistopora*-fauna as those which are found in the *Modiola*-Zone of the Bristol area.

2. A perfectly-typical and abundant  $K_1$  fauna, in which a *Modiola*-ostracod phase is developed.

3.  $K_2$  is poorly fossiliferous, but is succeeded by

4. A good development of the lower part of  $Z_1$ , containing the characteristic fossils in abundance.

5. The upper part of  $Z_1$  and the whole of  $Z_2$  are extensively dolomitized, wherefore fossils are scarce; there is, however, a well-marked fossiliferous band containing a  $Z_2$  assemblage, which corresponds to the similar band in the Chepstow area.

6. The base of C (the '*laminosa*-dolomite') contains a highly-fossiliferous oolitic limestone (the 'Crease Limestone'), wherein the fauna is identical with that which occurs at the same level in the Bristol area.

7. A succession of highly-interesting dolomites, but practically unfossiliferous.

8. A few thick limestone-beds (interstratified in many places with crystalline dolomites). This limestone (the 'Whitehead Limestone') exactly resembles in its lithological character certain beds of  $S_2$  in the Bristol area, and since it contains the same fossils (*Seminula*, *Productus*, etc.) it can be unhesitatingly referred to the Upper *Seminula*-Zone.

9. The 'Millstone-Grit.' Hence, in this district, the lowest 'Millstone-Grit' is of Upper *Seminula*-age.

#### (iv) THE CLEE-HILL AREA.

[I had an opportunity of examining the Carboniferous Limestone in this area during the recent visit of the Geologists' Association to Ludlow, under the presidency of Dr. A. Smith Woodward, F.R.S.

There are several very interesting problems connected with the peculiar development of the Carboniferous Limestone in this area; but these may be safely left in the hands of Mr. E. Dixon, who has undertaken their elucidation. From my present point of view, the main interest centres in the possibility of testing the value of the faunal sequence which has been established for the Bristol area at a point not far removed from the main Midland outcrop.

The *Cleistopora*-Zone may be dismissed at once, as showing the normal character.

The quarries at Oretton are of more interest, since they allow of a comparison between the result of zoning by the assemblage of brachiopods and corals, and that of zoning by the fish-facies. In his 'Notes on the Geology & Fossils of the Ludlow District,'<sup>1</sup>

<sup>1</sup> Proc. Geol. Assoc. vol. xviii (1904) p. 431.

Dr. Smith Woodward makes the following remarks on the fish-teeth and spines found in the Oreton Limestone :—

‘The fine teeth of *Orodus ramosus* and *Sandalodus Morrisi*, and the fin-spines named *Ctenacanthus major* and *Ct. sulcatus*, are identical with the fossil teeth and spines occurring in the Black Rock at Clifton, Bristol; but, so far as I have observed, there is no similarity between the Oreton fish-fauna and that met with in the bone-bed of the Lower Limestone-Shales at Clifton.’

In the Black-Rock Quarry at Clifton, fish-teeth and spines of the above types have been found at several levels, from the base up to a little beyond the middle of the quarry; but the beds in which they are most abundant occur at the top of this range. This may be expressed in faunal units, by saying that the teeth and spines found at Oreton occur in the Bristol area at any point in the *Zaphrentis*-Zone, from the middle of  $Z_1$  up to nearly the top of  $Z_2$ . Their maximum occurs nearly at the top of  $Z_2$ , above the maximum of *Schizophoria resupinata* and *Cliothyris glabristria*, and just below that of *Syringothyris cuspidata*.

I devoted a day to collecting in the Oreton Quarry, with the result that a specimen of *Orodus ramosus* was found below beds containing the following fossils :—

<i>Syringothyris cuspidata</i> (very abundant).	<i>Orthotetes crenistria</i> (common).
<i>Syringothyris</i> aff. <i>laminosa</i> .	<i>Reticularia</i> aff. <i>lineata</i> .
<i>Camarotoechia mitcheldeanensis</i> (very abundant).	<i>Productus</i> cf. <i>Martini</i> .
<i>Cliothyris glabristria</i> .	<i>Productus</i> aff. <i>pustulosus</i> .
<i>Cliothyris Royssii</i> (mut.).	<i>Michelinia</i> sp.
	<i>Zaphrentis</i> aff. <i>Phillipsi</i> .

If, now, the range-diagrams (Pls. XXVIII & XXIX, facing pp. 244 & 246) be consulted, it will be seen that the only possible position in which a vertical line can be ruled so as to cut the ranges of all the fossils cited above it, must lie within the *Zaphrentis*-Zone, and (in order to cut the ranges of *Michelinia* and *Syringothyris* aff. *laminosa*) the line must be drawn in  $Z_2$ . The form of *Productus* cf. *Martini* and the abundance of *Camarotoechia mitcheldeanensis* would suggest that the line must be drawn low down in  $Z_2$ .

I think it may be justly claimed that the two methods of zoning lead to identical results, and that the zonal position of the ‘Clee-Hill Marble’ is fixed beyond the possibility of question.

In a clay just above the limestone on the south side of the Clee Hills,<sup>1</sup> *Syringothyris* aff. *laminosa* is fairly common, and a single specimen of *Schizophoria resupinata* was found. This clay consequently occurs also in  $Z_2$ .

The overlying beds are of great interest, but the partial absence of fossils forbids their reference to any definite horizon.

The short distance at which the ‘Millstone-Grit’ occurs above

<sup>1</sup> I had the great advantage of the help of Mr. E. Dixon and Mr. O. T. Jones, in examining this portion of the Clee-Hill outcrop.

the clay already mentioned renders it probable that the entrance of the grit-facies was even earlier in the Cleve-Hill area than in the Mitcheldean district.]

#### (v) THE SOUTH-WALES OUTCROP.

[I have recently had the opportunity of studying the faunal sequence in both the 'North and South Crops'; the former in the neighbourhood of Kidwelly, and the latter in the district around Tenby. Mr. Ernest Dixon, B.Sc., F.G.S., of H.M. Geological Survey, very kindly acted as guide, and, as he had already made out the stratigraphical relationship of the different exposures, I was able to test the value of the faunal sequence without any waste of time.

Nothing could be more striking than the remarkable agreement of the faunal sequence in this area with that in the Bristol and Mendip areas. Even the rarest forms have been found at precisely the same level in the two regions. For example, a single specimen of a bryozoan ('*Chatetes radians*'?) has been found about the middle of  $S_2$  in the Avon section, and exactly the same fossil occurs in the same position near Tenby.

#### (a) The 'North Crop' in the Neighbourhood of Kidwelly.

The *Cleistopora*-Zone and Horizon  $\beta$  are typically developed in the 'Black Rocks' near Llanstephan.

No exposures in the *Zaphrentis*- or *Syringothyris*-Zones were observed.

The *Seminula*-Series is typically displayed in the large Fan Quarries, and here exactly the same forms occur at the same levels as in the Bristol area. For example, *Caninia cylindrica*, mut., *Lithostrotion basaltiforme*, var., *Productus*  $\theta$ , *Lithostrotion Martini*, and *Seminula ficoidea* characterize  $S_1$ . *Productus* aff. *Cora* (mut.  $S_2$ ) occurs in  $S_2$  with its usual associates, and here also *Alveolites* is not uncommon, together with *Cyrtina carbonaria*, which I have met with at the same level in the Wye quarries north of Chepstow, but have not yet recognized in the Bristol area.<sup>1</sup>

The lower part of  $D_1$  was not made out. The upper part of  $D_1$  is well shown, and exactly resembles the Sodbury development.

$D_2$  is splendidly displayed, and contains the characteristic forms.

Horizon  $\epsilon$  is here a calcareous stratum, and abounds in *Productus* aff. *scalbriculus* (cf. *Pr. costatus*), the form being identical with that found in the Avon section. Hence, the entrance of the 'Millstone-Grit' phase is, zonally, somewhat later than in the Bristol area, where Horizon  $\epsilon$  occurs within the base of the Grit.

<sup>1</sup> *Cyrtina carbonaria* is, however, very abundant at the base of  $S_2$  in the Weston area, where a bed crowded with this fossil was pointed out to me by Mr. Sibby. It has also been recently discovered at Wickwar (see above, p. 239).

## (b) The Tenby Area.

From Skrinkle Bay to Lydstep the series is almost complete, from the Old Red Sandstone up to (and including) the  $D_1$  subzone; not only is the faunal succession identical, but the relative abundance of individual species is almost the same in the Tenby and Bristol areas.

In ascending order we meet with:—

M. A basal series exhibiting a strong *Modiola*-ostracod phase.

K. The *Cleistopora*-Zone has all its characteristic fossils (*Productus bassus* was found at the base and *Cleistopora* near the top).

Z. The lowest beds of  $Z_1$  are, in the cliff-section, pinched out by a fault, but they are well shown in a neighbouring quarry.

$Z_2$  is well developed, and abounds in *Zaphrentes* with their usual associates, *Caninia* becoming common at the top.

$\gamma$  is moderately displayed.

C and  $\delta$ . { The *laminosa*-subzone is largely dolomitic; but the upper part of the *Syringothyris*-Zone is splendidly displayed, and bears a remarkable resemblance to the same level in the Mendip area.

$S_1$  is apparently poor in fossils; a block, probably derived from this level, contained *Productus* aff. *semireticulatus* and *Athyris* cf. *expansa*.

$S_2$  } are splendidly displayed and contain all the characteristic and  $D_1$  } fossils.

$D_2$  was not, at the time of my visit, definitely made out.

## (c) West Gower (Glamorgan).

In the Proceedings of the Bristol Naturalists' Society, Dr. W. B. Gubbin gives an account of the development of the Carboniferous Limestone in the west of the Gower Peninsula. The large collection of brachiopods and corals which he had made was submitted to me for determination, and the results of my examination are embodied in a supplementary note to his paper. In this note I point out how striking is the resemblance between the faunal sequence in West Gower and that in the Avon section.]

## V. COMPARISON WITH THE BELGIAN SEQUENCE.

As I have no personal knowledge of the Belgian rocks, and have only read the general accounts given in the Belgian text-books, the following comparison pretends to no great value; the great amount of valuable work, however, which has been done by Belgian geologists in zoning the Carboniferous Limestone, forbids the entire omission of such a comparison.

Since a large number of divisions are characterized solely by lithological characters, it is impossible to refer them to their correct place in my zonal system. It is, however, interesting to observe that the main horizon of dolomitization is the same in Belgium as in the Bristol area.

## A. Légende de la Carte Géologique de la Belgique, 1900.

In the short account of the Carboniferous Limestone given in this pamphlet, the brachiopods mentioned are all long-range forms; it is, therefore, impossible, without a knowledge of the associated fauna, to correlate the different stages with any great degree of accuracy.

- T<sub>1</sub>. Fauna cited: *Spirifer glaber*, *Sp. tornacensis*, and *Spiriferina octoplicata*.

Correlation: K, and probably Z<sub>1</sub>.

Reasons: *Spirifer tornacensis* belongs to the same species-group as *Sp. aff. clathratus*, which occurs in K<sub>1</sub>, becomes common in K<sub>2</sub>, and reaches its maximum in Z<sub>1</sub>. *Spiriferina octoplicata* is rare in K<sub>1</sub>, characteristic of K<sub>2</sub>, and extends to Z<sub>1</sub>. *Spirifer glaber* I do not know with certainty in the Bristol area.

- T<sub>2</sub>. Fauna cited: *Spirifer Konincki* (*Sp. cinctus*). Palechinids at the top.

Correlation: Z<sub>2</sub>.

Reasons: *Spirifer Konincki* is a member of the same species-group as *Sp. tornacensis*; it occurs in Z<sub>1</sub>, is probably commonest in Z<sub>2</sub>, and ranges on to γ. A specimen of *Palechinus* was found by Mr. W. H. Wickes at the top of Z<sub>2</sub>.<sup>1</sup>

- V<sub>1</sub>. Fauna cited: *Chonetes papilionacea*.

Correlation: C.

[Note.—In my system C forms the top of the Tournaisian, and not the base of the Viséan.]

Reason: Presuming that giganteid *Producti* are rare or absent, *Chonetes papilionacea* is only abundant in and just above γ, that is, in C.

- V<sub>2</sub>. Fauna cited: *Productus Cora* and *Pr. giganteus*.

Correlation: S<sub>2</sub> and D.

Reasons: *Productus Cora* is most abundant in S<sub>2</sub>; *Pr. giganteus* ranges from the upper part of S<sub>2</sub> through D.

B. The Works of Murlon<sup>2</sup> and Dewalque.<sup>3</sup>

I give my correlation without remark; the reasons will be apparent from my faunal tables.

ASSISE I. *Spiriferina octoplicata* towards the bottom; *Spirifer tornacensis* at the top.

Correlation: K and Z<sub>1</sub>.

<sup>1</sup> See above, p. 238, footnote.

<sup>2</sup> 'Géologie de la Belgique' vols. i & ii (1880-81).

<sup>3</sup> 'Prodrôme d'une Description géologique de la Belgique' 2nd ed. (1880) chap. vi.



Assise II. No fossils cited.

Assise III. *Orthis resupinata*.

Correlation:  $Z_2$  (lower part).

Assise IV. *Spirifer cuspidatus*.

Prof. Dewalque mentions the occurrence of *Amplexus coralloides* in the lower part.

Correlation:  $Z_2$  (upper part);  $\gamma$ ; lower part of C.

Assise V. Large *Euomphali*.

Correlation: top of C and  $\delta$  (the *Bellerophon*-Beds, in which large *Euomphali* are common).

Assise VI. *Productus Cora* and *Pr. giganteus*.

Correlation: S and D.

It is interesting to note that all the brachiopods mentioned by M. Mourlon and Prof. Dewalque occur in the same order in the Bristol area as in Belgium, and that they are correspondingly characteristic of the beds.

### C. The Parallelism of the Bristol and Belgian Sequence, by Prof. Max. Lohest.<sup>1</sup>

Palæontologically.—The conclusion that the general resemblance is complete rests on the occurrence at the same broad levels of the following fossils:—Small *Rhynchonella* in M; *Sp. tornacensis* in K (Prof. Lohest comments on the absence of *Spiriferina octoplicata* in K, but this is, of course, a mistake); teeth of fishes in Z; *Productus Cora* and *Pr. giganteus* in S and D.

Lithologically.—The writer cites the encrinital character of the Tournaisian, but comments on the absence of cherts from the Upper Tournaisian (*Zaphrentis*-zone). In the Viséan he states that the Avon section is continuously oolitic, and comments on the absence of compact dark limestones.<sup>2</sup>

The amount of similarity expressed by the above facts seems scarcely to warrant his conclusion.

To sum up the comparison:—Such facts regarding the Belgian sequence as I have been able to quote are in agreement with the sequence as here set out for the Bristol area; but the fauna is too scanty to allow of close correlation.

### VI. SUMMARY AND ANALYSIS.

The faunal sequence in the Bristol area is summed up in the table of ranges and maxima (pp. 243–247) and in the two range-diagrams (Pls. XXVIII & XXIX, facing pp. 244 & 246).

These diagrams depict the rise and decline of each species-group, and the positions at which its mutations are most abundant. To a

<sup>1</sup> Ann. Soc. géol. Belg. vol. xxii (1894–95) Mém. p. 7.

<sup>2</sup> The lithological character of the Viséan in the Avon section is erroneously described, as dark compact limestones form there a very characteristic feature of the *Seminula*-Zone.

first approximation, it has been demonstrated, beyond all question, that the relative position of the various groups is constant throughout the whole of the Bristol area: that is, that the species succeed each other always in the same order.

This statement holds true to a much higher degree of approximation, when we consider the corals alone, or the brachiopods alone. In fact, the only deviations from absolute constancy in this case consist in displacements in the positions of the maxima, as we pass from one point of the area to another. When, however, we measure the relative position of the corals by the brachiopod-sequence, or *vice versa*, there is a more important deviation which, although unimportant in a small area, would, if continued in the same sense to a considerable distance, need to be carefully allowed for.

We can therefore obtain a second approximation which shall hold true at considerable distances, by leaving the relative succession of the brachiopods unaltered, as also the relative succession of the corals, but by slightly displacing the one class relatively to the other. Very much more work must, however, be done in the Bristol and neighbouring areas (for example, in the Mendips and in South Wales) before the exact law of relative acceleration can be fixed.

In so far as the Bristol area is concerned, the table of ranges is sufficient to enable any worker to determine the horizon of any exposure which lies within the area, to a considerable degree of accuracy. If he registers all the fossils that he sees, and also notes their absolute and relative abundance, he will have no difficulty in determining, from the diagrams, the approximate horizon at which the exposure lies. I have tested this over and over again, and the results have always agreed with the position of the exposure as determined by stratigraphical reasoning (whenever such reasoning was possible). Before studying the neighbouring areas, I claimed that the main object of my prolonged work was to this extent achieved, that any fossiliferous exposure, lying within the Bristol area, could be horizoned to an adequate degree of approximation by the use of the range-tables; and I now go farther, and claim that the sequence established for the Bristol area holds good throughout the South-West of England and in South Wales.

### Analysis of the Faunal Characters of the Zones and Subzones.

#### The *Modiola*-Zone.

This zone is a pre-*Cleistopora*-Zone, in which the typical *Cleistopora*-fauna makes its entry, but in which this fauna is as yet very incompletely represented. The occurrence of *Modiola*-like forms associated with ostracods and *Spirorbis* does not in itself indicate any particular horizon, but rather marks a phase of sedimentation. The same association is to be found at several horizons in the Carboniferous Limestone of the neighbouring areas: for example,

in  $K_1$  and again in  $S_1$ . But it is a very suggestive fact that the transition from the Upper Old Red Sandstone into the Carboniferous Limestone, whenever that transition is continuous, is in the Bristol and surrounding areas always accompanied by this faunal phase.

So far as I am capable of judging, the *Modiola*-like form which occurs in  $S_1$  is quite distinct from *M. lata*; but, on the other hand, I cannot distinguish the form which occurs in  $K_1$  from the index-form of the *Modiola*-Zone. Hence, it must be confessed that the *Modiola*-Zone is not yet satisfactorily separated from the succeeding zone by the presence of distinct forms, but is merely an earlier series of beds in which the *Cleistopora*-fauna makes its entrance.

I do not, however, think that the *Modiola*-Zone should on this account be merged in the succeeding zone; for the Rhynchonellids are, at least in the Avon section, distinct from those occurring in the *Cleistopora*-Zone. It is also probable that some one among the numerous small gasteropods, which are so characteristic of these early beds, may ultimately afford a good zonal index.

### The *Cleistopora*-Zone.

Whenever corals can be found, this zone is distinctly separated off from the *Zaphrentis*-Zone above by the presence of *Cleistopora* and the absence of *Zaphrentis*. To a certain extent, however, this separation is a mere matter of definition. It rests upon the fact that directly the early *Zaphrentis*-fauna is fully established, *Zaphrentis* is found and *Cleistopora* is absent; but a sharp separation of the two zones is impossible, for, throughout the upper part of the *Cleistopora*-Zone, the brachiopods characteristic of the lower *Zaphrentis*-Zone enter one by one, and become gradually and continuously commoner.

Hence, from a purely-palæontological point of view, the separation of the 'Lower Limestone-Shales' is a complete impossibility. The faunal facies of the included limestones, at the top of the 'shales,' is practically identical with that of the lowest beds of the massive Limestone-Series, and the faunal continuity from the one into the other is perfect. Furthermore, the small variations at different points of the area in the faunal contents of the lowest beds of the massive Limestone-Series indicates that the junction of shales and limestone is not exactly at the same horizon throughout the area.

### The *bassus*- and *octoplicata*-subzones.

These two subzones are the expression of an important change of facies.

The *bassus*-subzone contains:—

- (1) Representatives of the earlier *Modiola*-fauna: for example, the same type of *Retzid* and the same form of *Clithyrus Royssii*.
- (2) Characteristic forms, such as *Productus bassus*, *Chonetes 'Buchiana'*.
- (3) A characteristic fish-fauna (see above, p. 253).

The index-fossil is subject to small geographical variation, but is widely distributed (Bristol, Mendips, Forest of Dean, Tenby), and I have not myself found it outside its own subzone.

The *octoplicata*-subzone contains:—

- (1) The early representatives of the *Zaphrentis*-fauna, which become more and more numerous in species and individuals, until at Horizon  $\beta$  a characteristic *Zaphrentis*-facies is developed.
- (2) Very few characteristic forms; the maxima of *Cleistopora* and of *Spiriferina octoplicata*, however, fall within this subzone.

### The *Zaphrentis*-Zone.

This zone witnesses faunal changes of the greatest importance.

- (1) At the base *Zaphrentids* enter; in the upper part the typical *Zaphrentis*-group becomes the dominant faunal factor; and at the very top of the zone the *Caninia*-group is evolved from a *Zaphrentis*-ancestor.
- (2) This zone includes the maximum development of the *Orthids*.
- (3) Starting with the maximum of *Spirifer*, it ends with that of *Syringothyris*.
- (4) The zone witnesses the mutational change of the small *Productus* cf. *Martini* into the typical *Pr. semireticulatus*.
- (5) At the top of the zone, *Chonetes papilionacea* supplants *Ch. cf. hardrensis* as the dominant *Chonetes*.
- (6) A characteristic fish-fauna is developed (see above, p. 253).

### The *clathratus*- and *resupinata*-subzones.

Whereas the *clathratus*-subzone exhibits a direct continuity and expansion of the *Cleistopora*-fauna, the *resupinata*-subzone witnesses the introduction of the *laminosa*-fauna (*Caninia*, *Syringothyris* aff. *laminosa*). The *resupinata*-subzone is well characterized by containing the maxima of *Zaphrentis*, *Schizophoria resupinata*, and *Cliothyris glabristria*.

### The *Caninia*-Zone.

If we adhere to a coral-basis for zonal division, *Caninia* is the only possible index that can be selected to succeed that of *Zaphrentis*; and, although I have ultimately decided to relegate this index to a secondary place, it has undoubtedly a very considerable value, both from the point of view of field-work and from an evolutionary standpoint.

The displacement of *Caninia* is based on the following considerations:—

- (1) When measured against the brachiopod-progression, the range of *Caninia* does not cover the same terms at different points of the Bristol area, as already pointed out (p. 185).

(2) If we take the limits of the *Caninia*-Zone to be defined by the two maxima of the gens *C. cylindrica* in the Avon section, the lower part of the zone contains a fauna which is characteristically Tournaisian, while the upper part exhibits a typically Viséan facies.<sup>1</sup>

The *Caninia*-Zone has consequently been divided into a lower subzone, the *Syringothyris*-Zone, which forms the top of the Tournaisian; and an upper subzone, which forms the base of the Viséan and is included in the *Seminula*-Zone, of which it forms the base.

### The *Syringothyris*-Zone.

This zone is characterized by the dying-out of the Tournaisian fauna and the evolution of the Viséan.

#### Examples :

- (1) *Orthotetes crenistria* occurs in profusion, as it does throughout the Tournaisian, but is associated with abundant *Chonetes papilionacea*.
- (2) *Caninia cylindrica*, which is enormously abundant at the base, gives rise by mutational change to the earliest member of the gens of *Cyathophyllum Murchisoni* (namely, *Cyathophyllum*  $\phi$ ).
- (3) *Productus Cora* becomes more abundant, and *Seminula* appears for the first time.
- (4) The earliest forms of *Lithostrotion* and of the Clisiophyllids occur very sparingly.

The zone is further characterized by the dominance of *Syringothyris*, which is represented by typical forms of *S. cuspidata* and *S. aff. laminosa*.

### The *Seminula*-Zone.

The abundance in individuals of *Lithostrotion*, *Seminula*, and giganteid *Productus* may be said to typify the Viséan facies.

The *Seminula*-Zone is characterized by recurring layers, made up almost entirely of the shells of *Seminula*. This zone is naturally divided into two subzones :—

The lower subzone or *semireticulatus*-subzone, in which the *Seminula*-fauna contains a few survivors of the Tournaisian facies, such as *Caninia*, *Syringothyris*, *Productus semireticulatus*.

The upper subzone or *Cora*-subzone, in which the *Dibunophyllum*-fauna is making its appearance. This subzone is characterized by the occurrence of a particular mutation of the gens of *Productus Cora*.

### The *Dibunophyllum*-Zone.

This zone is one of the easiest to distinguish, on account of its characteristic coral-fauna.

The attempt to separate an 'Upper Limestone-Shale' division, starting at the point where shales become prevalent in the Avon

<sup>1</sup> To avoid any interruption of the zonal discussion, the distinctness of these two faunas is demonstrated in a separate note.

section, is, from a palæontological point of view, indefensible, for the following reasons:—

(1) At the point where the shales start the *Dibunophyllum*-fauna is already well established, and the limestone-bands included in the shales contain a fauna which is indistinguishable from that in the topmost beds of the underlying massive Limestone-Series.

(2) In many localities the whole series is composed of massive limestones (for example, Tenby, the Mendips).

The essential fact in the *Dibunophyllum*-facies is the dominance of the Clisiophyllid-family, and the ultimate impression of a Clisiophyllidan character upon the whole of the coral-fauna.

### The $\theta\phi$ and *Lonsdalia*-Subzones.

The  $\theta\phi$ -subzone is characterized by Clisiophyllids belonging to several sections; the subzonal index itself represents a generalized division of the gens of *Dibunophyllum turbinatum*.

This subzone contains the maximum of *Cyathophyllum Murchisoni* in its type-form. In this form the Zaphrentid characters, which were so noticeable a feature of the early *Cyathophylla* (*Cyathophyllum*  $\phi$ ,  $C_2$  and  $S_1$ ), have, in the *Dibunophyllum*-Zone, become almost entirely lost.

In the *Lonsdalia*-Subzone the acme of the Clisiophyllidan phase of structure is reached.

*Lithostrotion* which, up to this subzone, forms the staple element in the Viséan coral-fauna, gradually adopts the Clisiophyllidan character and becomes merged in *Lonsdalia*. *Cyathophylla* of the type of *Cyathophyllum Murchisoni*, yielding to the same tendency, evolve forms of the type of *C. regium*.

The gens of *Dibunophyllum turbinatum* reaches its maximum specialization in the group represented by *Dibunophyllum*  $\psi$ .

### Horizon $\epsilon$ .

This horizon is well characterized by a group of scabriculate and spinose *Producti* (*Pr.* cf. *costatus* and *Pr.* cf. *semireticulatus*), and contains the remnants of a Carboniferous-Limestone facies in the presence of *Orthotetes crenistria* and *Productus Cora* (mut.).

The horizon being represented in widely-distant areas, and being the highest horizon at which a Carboniferous-Limestone fauna is found, forms a valuable datum-line for fixing the uppermost limit of the Carboniferous Limestone.

### The 'Millstone-Grit.'

The base of this lithological division is, as I have shown, a variable horizon. At Kidwelly it occurs immediately above Horizon  $\epsilon$ ; at Bristol it occurs immediately above  $D_2$ , so that Horizon  $\epsilon$  is included in the 'Millstone-Grit'; at Mitcheldean it

occurs in  $S_2$ ; and at Clee Hill it occurs soon after the close of the Tournaisian.

### Notes on the Distinctness of the Tournaisian and Viséan Faunas, tested by the Sequence in the Bristol Area.

The following genera of corals occur in the Tournaisian, but do not extend into the Viséan:—*Cleistopora* and *Zaphrentis*.

The following brachiopod-groups are confined to the Tournaisian:—

*Productus* cf. *Martini*.  
*Chonetes* cf. *crassistria*.  
*Chonetes* cf. *laguessiana*.  
*Leptena analoga*.  
*Schizophoria resupinata*.  
*Rhipidomella* aff. *Michelini*.

*Camarotæchia mitcheldeanensis*.  
*Eumetria* spp.  
*Spirifer* aff. *clathratus*.  
*Spiriferina octoplicata*.  
*Syringothyris cuspidata*.  
*Cliothyris glabrastria*.<sup>1</sup>

The following coral-groups are confined to the Viséan:—

*Alveolites septosa*.  
<sup>2</sup> *Lithostrotion* (all species).  
<sup>2</sup> The family of the Clisiophyllids  
 (including *Lonsdalia*).

*Cyathophyllum Murchisoni* (type).  
*Cyathophyllum regium*.

The great brachiopod-group of the giganteid *Producti* is practically confined to the Viséan (a few early forms of *Productus Cora* are met with below).

The following genera and gentes of corals pass up from the Tournaisian into the Viséan:—

*Syringopora*: the only common Tournaisian circulus is *Syringopora*  $\theta$ ; the circuli in the Viséan are of ramulose and geniculate types.

*Michelinia*: in the Bristol area I only know this genus in the Upper Tournaisian; it may extend into the base of the Viséan, where it is certainly rare.

*Caninia cylindrica*: by its mutations this gens undoubtedly links the Upper Tournaisian with the base of the Viséan, and, on this fact, the *Caninia*-Zone was originally founded.

*Amplexus* is essentially characteristic of the Upper Tournaisian, but probably extends, with *Caninia*, into the bottom of the Viséan.

*Cyathophyllum*  $\phi$  is characteristic of the very top of the Tournaisian and of the base of the Viséan.

The following genera and gentes of brachiopods pass up from the Tournaisian into the Viséan:—

*Productus semireticulatus*: this gens, by its mutations, constitutes a genuine link between the two divisions.

*Chonetes papilionacea* may be defined as a Viséan form, which has already become important in the Upper Tournaisian.

*Orthotetes crenistria* is also a link of great importance; but, whereas it is enormously abundant throughout the Tournaisian, it is rare in the Viséan.

*Seminula* is an essentially-Viséan genus, and is only found rarely at the very top of the Tournaisian.

<sup>1</sup> See note under *Cliothyris glabrastria*, p. 298.

<sup>2</sup> Very few early forms have been found in C.

*Cliothyris*: it is doubtful whether the form found in  $S_1$  really belongs to this genus.

*Syringothyris* aff. *laminosa* is found rarely in  $S_1$ , but is essentially characteristic of the top of the Tournaisian.

From the foregoing analysis, it seems to me beyond question that, in the Bristol area, the division of the Carboniferous Limestone into an upper and a lower part is thoroughly justified on purely-palæontological grounds, and is also of great practical utility. In recognition of the great amount of exact work done by Belgian geologists, in elucidating the palæontological sequence in the Carboniferous Limestone of their own country, we are, I think, bound to accept the names which they have adopted for the two divisions.

On the other hand, the designation Dinantian, as including the whole of the Carboniferous Limestone, seems hardly justified by the continuity or clearness of the sequence in the district which has suggested the title. It cannot, however, be denied that it would be extremely convenient to have a single designation (other than a misleading lithological term) which should include the 'Lower Limestone-Shales' at the base and the 'Upper Limestone-Shales' at the top, as well as the main mass of limestone.

[As I have pointed out above, the detailed examination of the faunal sequence in the Bristol area demands that the division-line between a lower series (Tournaisian) and an upper (Viséan) should be drawn at the top of the *Syringothyris*-Zone. But, if I am correct in correlating the Lower Viséan of the Belgian Geological Survey with the *Syringothyris*-Zone of the Bristol area, the terms Tournaisian and Viséan, as employed by me in this paper, do not bear their original connotation: the zone C being included in the Viséan by Belgian geologists, and in the Tournaisian on my system.

Under these circumstances, it seems better to avoid all chance of confusion by employing new indices for the whole of the Carboniferous-Limestone Series as developed in the South-West of England and in South Wales, as well as for its two great divisions.

I consequently suggest the following classification:—

AVONIAN .....	{	KIDWELLIAN ...	{ <i>Dibunophyllum</i> .
			{ <i>Seminula</i> .
	{	CLEVEDONIAN ...	{ <i>Syringothyris</i> .
			{ <i>Zaphrentis</i> .
			{ <i>Cleistopora</i> .

Avonian, as synonymous with Lower Carboniferous, seems warranted by the completeness of the sequence in the Avon section (Bristol) and by the fact that the Avon Gorge has been recognized as a classical section, since its minute description in Trans. Geol. Soc. ser. 1, vol. iv (1811–17) p. 197 & vol. v (1818–21) p. 95, by George Cumberland.

Clevedonian satisfactorily connotes the Lower Avonian, since, in the neighbourhood of Clevedon (Somerset):—

- (1) The zones of *Cleistopora*, *Zaphrentis*, and *Syringothyris* are all well-displayed; and
- (2) The Upper Avonian is practically absent.



Kidwellian is suggested<sup>1</sup> as the index of the Upper Avonian, since, in the neighbourhood of Kidwelly (Caermarthen):—

- (1) The Lower Avonian appears to be very incompletely developed;
- (2) The *Seminula*- and *Dibunophyllum*-Zones are magnificently displayed.—A. V., April 8th, 1905.]

### Epitome of Conclusions.

1. The faunal sequence is constant throughout the extended area in the South-West of England and South Wales.
2. The study of the fauna affords clear evidence of evolution.
3. The Tournaisian and Viséan facies are essentially distinct.
4. The separation of a 'Lower Limestone-Shale' Series at the base, and an 'Upper Limestone-Shale' Series at the top, is opposed to the palæontological evidence.
5. The base of the 'Millstone-Grit' is not a definite level, but occurs at different levels in the Viséan in different localities.
6. The transition of the Upper Old Red Sandstone into the Carboniferous Limestone, where perfectly continuous, was accompanied by a particular faunal phase.

I owe so much to the kindness of other geologists, who have so readily helped me during my work, that an adequate acknowledgment is entirely out of the question.

My thanks are due to Dr. A. Smith Woodward, Dr. F. A. Bather, and Mr. Lang, at the Natural History Museum; to Mr. E. T. Newton, Mr. J. Allen Howe, and Mr. H. A. Allen, at the Museum of Practical Geology; and to Mr. H. Bolton, at the Bristol Museum, for the great assistance which they have given me during my work at the collections housed in their respective institutions. Also to Mr. H. C. Playne for permission to examine the Clifton-College collection; and to Prof. S. H. Reynolds for much assistance during my work at the Stoddart Collection, preserved in University College, Bristol.

I have also to thank Dr. Bather for naming crinoids, Mr. Lang for great assistance with the bryozoans, Dr. Wheelton Hind for naming my lamellibranchs, and Mr. J. F. Walker for very generously assisting me in brachiopod work by the loan of papers and specimens.

To Prof. Lloyd Morgan I am indebted for much valuable information, and above all for his unwearying appreciation and encouragement.

I have to thank Mr. E. Dixon for his invaluable help during my visit to the Kidwelly and Tenby areas.

To Prof. S. H. Reynolds I am under a deep obligation for his continuous help, and in particular for his very valuable assistance in the examination of the Sodbury section.

<sup>1</sup> The final acceptance of this index-term must, however, await the detailed results of the present re-survey of the Kidwelly area by the officers of H.M. Geological Survey.

To Mr. T. F. Sibly I am deeply indebted for continuous help in the field-work, and without his assistance the examination of the Bristol area would have been far less comprehensive than it is.

I have to thank Mr. W. H. Wickes and Mr. L. Richardson for some of my finest specimens.

To Mr. J. W. Tutchter I owe the excellent photographs (reproduced in Pls. XXII-XXVI) illustrating this paper, to the preparation of which he has devoted so much care. Several of the photographed specimens belong to his fine collection.

I have also to thank the Director of H.M. Geological Survey and the Committee of the Bristol Museum, for permission to photograph specimens in the Jermyn-Street and Bristol Museums.

I cannot sufficiently thank Mr. L. L. Belinfante, M.Sc., for the very great trouble which he has taken in editing an extremely-technical paper.

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#### VII. NOTES ON THE CORALS AND BRACHIOPODS REFERRED TO IN THE FAUNAL LISTS.

The object of these notes is merely to explain the faunal lists, by indicating the interpretation which I intend each name to bear. For this purpose, no historical research into the priority of names is necessary, nor is it absolutely essential that the names should cover the original type. So long as the explanation and references, here given, are sufficient to particularize the form which each name is intended to denote, my object will have been completely achieved.

On the other hand, I have endeavoured to employ each name in what I believe to be the meaning attached to it by accepted authorities, so that reference to easily-accessible figures is, in most cases, sufficient. For example: *Productus Cora* is employed in the sense in which I believe it to have been used by Davidson, notwithstanding the fact that it is doubtful whether the original type of the species is very closely allied to the forms here intended.

In the case of important stratigraphical forms which only bear a limited resemblance to forms already figured, I have merely indexed the forms by the addition of the letters  $\theta$ ,  $\phi$ ,  $\psi$  to the generic name. This method has the advantage of conveying definite information, without asserting relationship to somewhat similar forms the position of which, on the chronological scale, is at present unknown. Should both the Bristol form and the one already figured, to which it bears a certain resemblance, be found, later, to occupy the same chronological position, it will be rendered probable that both are mere local variants of the same gens, and they can then receive the same name.

I have followed the same plan in cases where I consider that very distinct forms have been included under the same name, and where I wish to indicate only one of the forms so included.

## (1) NOTES ON THE CORALS.

## Introductory Explanation.

For the determination of the corals, horizontal sections are indispensable, but the nature of the vertical section can usually be deduced from an examination of the horizontal section.

Calicular views are of far less value, because they are rarely met with in the field, and, when seen, are as a rule partly obscured by matrix, or destroyed by weathering; they also give a misleading idea of the internal structure, both by exaggerating the relative importance of the secondary series of septa and by disguising that of the tabulæ. The horizontal sections figured in Pls. XXII–XXIV are photographed from thin slices by Mr. J. W. Tutchet, by a process which he has himself invented.

The full titles of the works, referred to in these notes, are as follows:—

- MICHELIN, H.: 'Iconographie Zoophytologique.' 1840–1847.  
 M'Coy, F.: 'Synopsis of the Characters of the Carboniferous-Limestone Fossils of Ireland.' Dublin, 1844. Folio.  
 M'Coy, F.: 'Systematic Description of the British Palæozoic Fossils in the Geological Museum of the University of Cambridge.' 1851.  
 MILNE-EDWARDS, A., & HAIME, JULES: 'Monographie des Polypiers fossiles des Terrains Palæozoïques' [*ex Arch. Mus. Hist. Nat.* vol. v]. 1851.  
 MILNE-EDWARDS, A., & HAIME, JULES: 'Monograph of the British Fossil Corals' pt. iii (1852) pp. 150 *et seqq.* Palæontographical Society.  
 THOMSON, JAMES: 'On the Development & Generic Relation of the Corals of the Carboniferous System of Scotland' *Proc. Phil. Soc. Glasgow*, vol. xiv (1883) p. 296; and earlier papers of the same author, in the same Proceedings.  
 VAUGHAN, ARTHUR: 'Notes on the Corals & Brachiopods obtained from the Avon Section & preserved in the Stoddart Collection' *Proc. Bristol Nat. Soc.* n. s. vol. x (1903) p. 90.

See also the general introductory remarks on p. 266.

## Alveolites.

## ALVEOLITES SEPTOSA (Flem.).

Here I include:—

- A. septosa*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' p. 157 & pl. xlv, figs. 5–5 *b*.  
*A. depressa*, Edwards & Haime, *ibid.* p. 158 & pl. xlv, figs. 4–4 *a*.

The relation of these forms is discussed in *Proc. Bristol Nat. Soc.* n. s. vol. x (1903) p. 95.

## Syringopora.

It is very doubtful whether the so-termed 'species' of this genus are anything more than circuli.

## SYRINGOPORA cf. DISTANS, Fischer.

As interpreted in Edwards & Haime, 'Polypiers Foss. Paléoz.' p. 286 & pl. xx, fig. 1. See also *Proc. Bristol Nat. Soc.* n. s. vol. x (1903) p. 98.

The Bristol forms which I include here have the following characters:—

The tubes are moderately spaced, and have a general parallel trend, but are subramulose at considerable intervals.

Horizontal Section.—Moderately-spaced single rings and dumbbell-like pairs are almost equally numerous; elongated intersections are rare.

Range.—Throughout the Viséan.

*SYRINGOPORA* cf. *GENICULATA*, Phill.

As interpreted in Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 163 & pl. xlv, figs. 2-2 *a*.

Tubes closely packed and parallel; connectors very numerous.

Horizontal Section.—Closely-placed rings, the majority of which are connected.

Range.—I only know the typical form from D<sub>1</sub>.

*SYRINGOPORA* cf. *RAMULOSA*, Goldf.

As interpreted in Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 161 & pl. xlv, figs. 3-3 *c*.

Tubes greatly spaced and strongly flexed; the connectors are of equal diameter with the tubes. The Bristol form has narrow tubes.

Horizontal Section.—The intersections are very sparsely distributed, and elongated intersections are frequent.

Range.—I only know this form with certainty from S.

*SYRINGOPORA* *θ*. (Pl. XXII, figs. 1 & 1 *a*.) (Cf. *S. lava*, Phill.)

Corallites cylindrical, and arranged in parallel grouping. Connecting-tubes distant. Genucation scarcely noticeable at the junctions of the corallites with the connecting-tubes. Tabulæ distant and funnel-shaped.

In a horizontal section, only a few of the cross-sections are connected, and there is seldom more than one oval tabular intersection, within the cross-section of a corallite.

Diameter of corallites = 2 to 2½ millimetres. The distance between the axes of adjacent corallites averages 4 mm.; the distance apart of connecting-tubes averages 10 mm.

*SYRINGOPORA* cf. *RETICULATA*, Goldf.

Tubes very narrow, parallel, and close-set.

Horizontal Section.—The frequent grouping of four or five tubes, in such a manner that their cross-sections form short chains, produces a marked *Halysites*-like appearance.

Range.—This form is highly characteristic of C<sub>1</sub>.

**Cleistopora.**

*CLEISTOPORA* aff. *GEOMETRICA* (Edwards & Haime).

As interpreted in Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 99-100 & pl. i, fig. 3.

**Michelinia.**

The reference of specimens to particular species can only be approximate, since the characters of the base are seldom seen. I have consequently, in most cases, contented myself with recording the genus.

**MICHELINIA cf. FAVOSA (Goldf.).**

As interpreted in Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 154 & pl. xlv, figs. 2 *b*-2 *c*.

Here may be placed the specimens from  $Z_1$ .

**MICHELINIA cf. TENUISEPTA (Phill.).**

As interpreted in Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 155 & pl. xlv, figs. 1-1 *b*.

Here I include tall forms, composed of few corallites, with thin walls. I have only seen a few specimens from  $Z_2$ .

**MICHELINIA MEGASTOMA (Phill.).**

As interpreted in Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 156 & pl. xlv, figs. 3-3 *b*.

Here I include forms with thick walls and large corallites.

This is probably the commonest species; it characterizes the top of  $Z_2$  and the lower part of C.

**Amplexus.****AMPLEXUS cf. CORALLOIDES, Sow.**

As interpreted in Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 173 & pl. xxxvi, figs. 1-1 *e*.

I include here all the large cylindrical forms of the genus.

**Zaphrentis (restricted).**

= *Zaphrentis* as employed by Edwards & Haime, with the omission of the group of *Z. cylindrica*, which is here referred to *Caninia*.

**ZAPHRENTIS aff. PHILLIPSI, Edwards & Haime.** (Pl. XXII, figs. 2-2 *e* & text-fig. 2, p. 270.)

Includes:—

{ *Zaphrentis Phillipsi*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 168 & pl. xxxiv, figs. 2-2 *b*.

{ *Zaphrentis Griffithi*, Edwards & Haime, *ibid.* p. 169 & pl. xxxiv, figs. 3-3 *a*.  
Prox. *Zaphrentis Phillipsi*, Edwards & Haime, 'Polypiers Foss. Paléoz.' p. 332 & pl. v, fig. 1.

Non *Zaphrentis Phillipsi*, Thomson, Proc. Phil. Soc. Glasgow, vol. xiii (1881-82) p. 222 & pl. iv, figs. 3-3 *a*.

Corallum small, conical, and usually curved. The length seldom reaches 3 centimetres, average specimens being under 2 cm. long. Epitheca thick, with strong rugæ. Calyx very deep, with a thin margin.

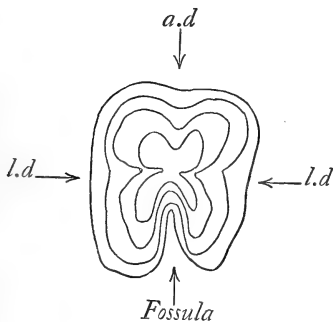
Primary septa strongly thickened at the wall and also at their inner ends, where they are attached to the tabulæ.

The secondary septa are rudimentary, and are only represented, in a horizontal section, by a slight projection of the wall between two primary septa; they are, however, more conspicuous in the calyx.

Grouping of the primary septa.—On each side of the fossula there is a lateral group, composed of from five to seven septa, which unite at their inner ends to form the walls of the fossula; the remaining (thirteen to fifteen) septa form a nearly-continuous antifossular series. There is a single, long but thin, fossular septum.

Septal breaks and fossula.—The fossula forms a conspicuous break between the two lateral groups. Between each lateral group and the antifossular group, there is usually a less-marked septal break indicated by:—

Fig. 2.—*A tabula* of *Zaphrentis aff. Phillipsi*, represented by contours.



*a.d.* = Antifossular depression.  
*l.d.* = Lateral depression.

- (1) The stronger development of a secondary septum, which bends round and unites with the antifossular group.
- (2) The stronger development of the two terminal septa of the antifossular group, which frequently join across the centre of the section, so as to bisect it.

This feature is extremely marked in the very young stage, when the fossula is inconspicuous.

There is, usually, some indication of an antifossular septal break.

The tabulae have a complex flexure, but their essential character is that of a dome with four grooves down its sides, as represented in the accompanying contoured diagram (fig. 2).

Discussion.—The original figure of *Zaphrentis Phillipsi* in the 'Polypiers Foss. Paléoz.' pl. v, fig. 1, differs from the Bristol form in the presence of:—

- (1) More numerous septa, which are consequently less widely spaced.
- (2) Greater radial symmetry.
- (3) Indistinct lateral septal breaks.

On the other hand, the description given in the 'Monogr. Brit. Foss. Cor.' pt. iii, was largely founded upon specimens in the Bristol Museum, which were derived from the Mendip area, and are quite typical Bristol forms. The authors attribute the differences between this form and their type to the suggestion that all the British specimens that they had examined were young forms. From the examination of thousands of specimens, I am, however, convinced that the above differences are constant, and represent true variations of the adult stage. The position of the fossula is emphasized

by Edwards & Haime as an important diagnostic character; but I have collected, from the same bed, specimens in which the fossula is as often on the short side of the horn as on the longer one: whereas, in all the specimens, the characters of the septa and tabulæ are identical.

*Zaphrentis Griffithi* agrees with our forms in all the essential characters of septal grouping and tabular flexure, and only differs in its short and broad form and in its more numerous septa.

*Zaphrentis Phillipsi* (Edwards & Haime), Thomson, is illustrated by a very inadequate figure. From the author's description, it is evident that the form with which he deals differs markedly from ours in the following characters:—

The septa are thin, and pointed towards their inner ends.

Three of the septa extend into the fossula, of which the central one is considerably the shortest and not more than half a line in length.

ZAPHRENTIS aff. CORNUCOPIÆ (Mich.),<sup>1</sup> Edwards & Haime.  
(Pl. XXII, figs. 3–3 d.)

Prox. *Zaphrentis cornucopiæ*, Edwards & Haime, 'Polypiers Foss. Paléoz.  
p. 331 & pl. v, figs. 4–4 a.

Form: elongate, cornute. The average length is between 3 and 4 centimetres. Epitheca with indistinct rugæ and a few distant constrictions. Calyx circular, deep and cup-shaped, with bevelled rim.

Primary septa strongly thickened at the wall, 35 to 40 in number, close and very regularly spaced, so that the symmetry is strikingly radial.

Secondary septa short and thick, just projecting beyond the thick wall. Wall dense and thick, being formed by the thickening of the ends of both series of septa.

Septal breaks and fossula.—The only conspicuous break is the fossula, which extends from the centre to the wall of the coral, and is bounded by vertical walls; in cross-section, it is slit-like and typically keyhole-shaped.

The fossula is open throughout its length, but, near the outer wall, it is constricted by the elongation of two secondary septa, which bend round and become united with its lateral walls; a single rudimentary primary septum projects for a very short distance into the fossula. The fossula is, in every specimen that I have seen, on the side of the longer curve of the horn.

Two inconspicuous lateral breaks are usually indicated by the elongation and bending of a secondary septum on each side.

In the very young form, the structure approximates to that seen in *Zaphrentis* aff. *Phillipsi*; the horizontal section is bisected by the meeting of the two terminal septa of the antifossular group,

<sup>1</sup> The figure given by Michelin, 'Icon. Zooph.' pl. lix, fig. 5, is characterized by Edwards & Haime ('Monogr. Brit. Foss. Cor.' pt. iii, p. 167) as a very bad figure; it agrees better, however, in elongated form, with the specimens common in the Bristol area than does the figure in the 'Polypiers Foss. Paléozoïques.'

while the fossula is less marked and is occupied by a prominent primary septum.

The tabulæ are domes, with only one strong groove which forms the fossula.

Discussion.—The species, as described and figured by Edwards & Haime, differs from our specimens in having (1) a short, broad-angled form; and (2) an oval calyx. It agrees, however, in all the essential characters of septal grouping and tabular flexure.

Evolution and mutation.—From the characters of very young specimens, it is most probable that *Zaphrentis* aff. *cornucopiae* was derived from an ancestor closely allied to *Z.* aff. *Phillipsi*; on the other hand, the radial symmetry of the septa and the flexure of the tabulæ indicate early *Caninia*-like characters. These suggestions are in agreement with the time-range of *Zaphrentis* aff. *cornucopiae*; it makes its first appearance in  $Z_2$ , after *Z.* aff. *Phillipsi* was well established, and reaches its maximum at the top of  $Z_2$ , where *Caninia* begins to appear; it dies out in the lower part of the *Syringothyris*-Zone.

**Caninia**, Michelin; emended, M'Coy, 'Brit. Palæoz. Foss.' p. 28.

= *Zaphrentis cylindrica* and allies, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 171.

= *Campophyllum*, Thomson (*non* Edwards & Haime), Proc. Phil. Soc. Glasgow, vol. xiv (1883) p. 375.

= *Caninia*, Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 102.

This genus resembles *Zaphrentis* in the well-developed fossula and the consequent axial symmetry. It differs from *Zaphrentis* in:

- (1) The predominance of the tabulate over the septate structure.
- (2) The insignificance of the outer wall and its replacement by a thick shell of vesicles.

The genus *Caninia* was originally founded by Michelin to cover all corals having deep fossular depressions, the type being *C. gigantea* (in which were included both the Devonian and the Carboniferous forms). M'Coy restricted the genus to its type-species, and re-defined it by the vesicular character of the wall.

The differences of this genus from *Campophyllum*, Edwards & Haime, and from the Carboniferous *Cyathophylla* will be noticed later (p. 276). These differences have already been discussed in Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 102-103.

#### CANINIA CYLINDRICA (Sculer).

*Siphonophyllia cylindrica*, Scouler, in M'Coy, 'Syn. Carb. Limest. Foss. of Ireland' p. 187 & pl. xxvii, fig. 5.

*Zaphrentis cylindrica*, Edwards & Haime, 'Polypiers Foss. Palæoz.' p. 339.

*Caninia gigantea*, M'Coy, 'Brit. Palæoz. Foss.' p. 89.

*Zaphrentis cylindrica*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii, p. 171 & pl. xxxv, figs. 1-1 b.

(?) *Campophyllum Murchisoni*, *C. cylindricum*, *C. giganteum*, Thomson, Proc. Phil. Soc. Glasgow, vol. xiv (1883) pp. 376, 377, 378 & pl. vii, figs. 4, 9, 11.



The general characters of this species have been sufficiently described by previous writers, but the following notes are introduced to explain the mutational stages.

The central portion of the calyx, at an adult stage of growth, is a broad, flat tabula, surrounded by a circular, moat-like groove; the wall of the calyx is very thick, and its inner face slopes down to the groove.

The septa are numerous, and are strongly developed in the region of the groove; from this region they stretch inwards, along the face of the tabula, and outwards, along the sloping face of the wall. It is, as a rule, only in the immediate neighbourhood of the groove that the prolongations of the septa are sufficiently tall to reach from tabula to tabula, or from one layer of the vesicles, which form the inner surface of the wall, to the next layer. Hence, the characters of a horizontal section are as follows:—

The outermost vesicles of the thick wall usually show no septal projections, but these projections become longer and stronger as we pass inwards.

The septa usually are strongly thickened in the region of the groove, though not uniformly so all round the whole circumference, the septa in the neighbourhood of the fossula being always the most strongly thickened. This phenomenon is probably connected with the fact that the tabulae slope down to the fossula.

The septa are cut off sharply where the plane of section cuts across a tabula. The interruptions of the septa, and the abrupt change from a thick septum to a thin one, are due to the fact that the plane of section, after cutting through one tabula, intersects the septa which lie on the next lower tabula.

### Mutational Forms.

#### MUTATION $\gamma$ . (Pl. XXIII, fig. 1.)

This form is characterized by the slight extension of the septa over the vesicular wall, so that, in a horizontal section, the septa are only represented by short projections from the vesicles in this region.

#### MUTATION $S_1$ . (Pl. XXIII, fig. 1a.)

*Caninia cylindrica*, var. *bristolensis*, Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 103 & pl. i, fig. 4.

Here, the septal prolongations are more strongly developed over the vesicular wall, so that, in a horizontal section, the external vesicular area is delicately radiated by continuous prolongations of the septa. There is also a greater development of vesicles in the interseptal spaces.

In both these characters there is an approach towards a Cyathophyllidan structure, but the strong fossular depression, and the marked thickening of the septa in the middle of their length, separate this form as a true *Caninia*.

### The Carboniferous Cyathophylla.

The characters of the typical members of this single, comprehensive gens are as follows :—

- (1) Very numerous septa, alternately long and short.
- (2) All the septa are of nearly-equal thickness, and the thickness of each septum is almost uniform along its length.
- (3) The long septa reach nearly, or quite, to the centre; and all the septa extend to the wall.
- (4) In the external area, which is radiated by both series of septa, the interseptal spaces are crowded with small vesicles.
- (5) In the medial area, which is radiated only by the long septa, the interseptal spaces contain few vesicles.

#### CYATHOPHYLLUM $\theta$ . (Pl. XXIII, fig. 2.)

This type may be considered to represent the *Zaphrentis*-like ancestor of the gens.

Form : short, cornute, and broad-angled.

The septa are of uniform thickness along their length, and only differ, one from the other, in being alternately long and short; they are considerably more wide-spaced than is the case in the more typical members of the gens. The long septa do not reach the centre, which is occupied solely by the broad tabulæ.

There is a strongly-marked septal break at the fossula, which is occupied by a single, short septum; there is, also, a lateral interruption of the septal sequence, marked out by the greater elongation of one of the shorter septa.

The interseptal vesicles are distributed, as in the typical members of the gens.

The tabulæ are broad and vaulted, with a deep and narrow depression which forms the fossula.

#### CYATHOPHYLLUM $\phi$ . (Pl. XXIII, figs. 3-3*b*.)

= *Cyathophyllum Stutchburyi*, Edwards & Haime (*pars*) 'Monogr. Brit. Foss. Cor.' pt. iii, p. 179.

Besides the characters already noted as common to all the typical members of the gens, the following characters are important :—

- (1) In a vertical section :

The tabulæ are low, broad plates, which occupy the whole region within the inner wall, but only the minority stretch continuously across from side to side; the majority are merely very broad, low vesicles which overlap one another. In this respect, the vertical section differs from that of a *Caninia*.

- (2) In a horizontal section :

The numerous interseptal vesicles in the medial area represent the intersection of the tabular vesicles by the plane of section.

The centre is usually free of septa, and occupied only by a few curvilinear intersections with the tabular vesicles. In the adult, this area is very reduced in size by the extension of the long septa almost or quite to the centre; but in the young form (see Pl. XXIII, fig. 3*a*) there is a broad, central tabular area, free of septa. The

fossula is merely indicated as a narrow septal break, occupied by a single primary septum of shorter length than the others, and by the small, inward shift of the tabular intersections in that region (as in the representation, on a contoured map, of a valley in a hillside). The fossula is much more strongly marked in the young form.

### (3) External form:

The general form is an elongated cone.

The middle of the floor of the calyx is flat, in the few specimens in which I have been able to see this feature.

Discussion.—Fig. 4, pl. xxxiii, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' undoubtedly represents the species that I am here describing; but, as I have shown in Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 110 *et seqq.*, *Cyathophyllum Stutchburyi*, Edwards & Haime (as originally defined<sup>1</sup> by certain external characters), is identical with *C. Murchisoni*, Edwards & Haime.

In their later work,<sup>2</sup> Edwards & Haime give an almost identical definition of the species, although they draw attention to the vertical section, which almost certainly belongs to a specimen of *Cyathophyllum*  $\phi$ .

They group, however, under *C. Stutchburyi* certain short, turbinate forms, with a broad everted rim to the calyx. I have examined the vertical sections of similar forms, and I find that the central structure is purely vesicular, and agrees entirely with that characteristic of *Cyathophyllum regium*. These forms I have therefore separated, as simple forms of *C. regium*.

Under these circumstances, it does not seem possible to adopt *C. Stutchburyi* as the name of our species, and I have tentatively represented it by *Cyathophyllum*  $\phi$ .

### CYATHOPHYLLUM MURCHISONI, Edwards & Haime.

Besides *C. Murchisoni*, as defined and figured by Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 178 & pl. xxxiii, figs. 3-3 b, I include here all those elongate specimens of *C. Stutchburyi* which have not an essentially-tabulate structure.

The characters of this species that essentially distinguish it from *Cyathophyllum*  $\phi$ , are the predominance of purely-vesicular structure in the central space and the extreme reduction of tabulate structure. A full account of this species is given in Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 110-14.

### CYATHOPHYLLUM REGIUM, Phil.

I here include:—

*Cyathophyllum regium*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 180 & pl. xxxii, figs. 1-4 a.

*Cyathophyllum Stutchburyi*, Edwards & Haime, *ibid.* pl. xxxi, figs. 1 & 1 a.

In Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 114-15, I have given reasons for regarding the short, turbinate type of

<sup>1</sup> 'Polypiers Foss. Paléoz.' 1851, p. 373.

<sup>2</sup> 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 179 & pl. xxxi, figs. 1-2 a.

*Cyathophyllum*, with broad everted rims, as the simple form of *C. regium*.

The essential structure consists in the vaulted arrangement of fine vesicles in the central space, and in the absence of tabulæ.

### Evolution and Mutation of the Carboniferous *Cyathophylla*.

All the forms that we have just considered constitute a single gens, in the exact sense in which that term is here employed.

It seems probable that, at the top of  $Z_2$  or in  $\gamma$ , occurred the ancestral *Zaphrentis*-like form, from which *Caninia*, *Lithostroton*, the Carboniferous *Cyathophylla*, and the Clisiophyllids were evolved. *Cyathophyllum*  $\theta$ , from just below  $\gamma$ , only differs from *Zaphrentis* in the development of a vesicular external area. The relationship of such a form to *Zaphrentis* aff. *cornucopiæ* is, in reality, very close; for, if a horizontal slice of *Z. aff. cornucopiæ* be examined under a microscope, the thick wall is seen to be veined by wavy, discrete, dark lines which run between the ends of adjacent septa, and the dense wall is due to the deposit of stereoplasma on each side of these dark lines. It is, then, possible that the dense wall of *Zaphrentis* aff. *cornucopiæ* differs from the vesicular one of *Cyathophyllum*  $\theta$ , only in the amount of the deposit of stereoplasma.

*Cyathophyllum*  $\phi$ , which characterizes the *Syringothyris*-Zone and reaches its maximum at  $\delta$ , resembles *Caninia* in the character of its tabulæ. It is, therefore, an interesting instance of parallel development and coæval assimilation.

*Cyathophyllum Murchisoni* shows a further divergence from the simple tabulate structure. It reaches its maximum at the bottom of  $D_1$ .

In *Cyathophyllum regium*, which is confined to  $D_2$ , the original tabulate structure is entirely lost, and the Clisiophyllidan tendency is exhibited in the vaulted layers of fine vesicles which occupy the central space.

### **Campophyllum**, Edwards & Haime (*non* Thomson).

This genus is distinguished from *Caninia* by the following characters:—

- (1) Almost perfect radial symmetry, due to the uniformly-developed ring of short, thick septa.
- (2) The absence, or very feeble development, of a fossular depression.
- (3) The uniformly-thick shell of vesicles between the two walls.
- (4) The strongly-developed outer wall.

[See also Proc. Bristol Nat. Soc. vol. x (1903) p. 102.]

### **CAMPOPHYLLUM** aff. **MURCHISONI**, Edwards & Haime.

I here include, tentatively:—

- (1) *Campophyllum Murchisoni*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 184 & pl. xxxvi, figs. 2, 2a, 3.
- (2) *Campophyllum* aff. *Murchisoni*, Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 116 & pl. i, fig. 5.

It will be safer to wait for more material, before attempting to

separate the different forms which I have tentatively referred to this group. All the specimens that I have collected occur in the *Dibunophyllum*-Zone.

Form (1) has a narrow external area, of a *Lithostrotion*-type of structure. Form (2) is characterized by strong rugæ and a thick outer wall; the septal ring is separated from the outer wall by very large vesicles. The septa are well spaced.

### Lithostrotion.

Until a very much larger series of accurately-horizoned specimens has been collected and studied, it will be vain to attempt a natural classification of this group founded upon true evolutionary modification. I have, consequently, adhered, as closely as possible, to the artificial system of species recognized by Edwards & Haime in their 'Monograph of the British Fossil Corals.' It is, however, important to draw attention to the principal modifications which affect the typical *Lithostrotion*-structure.

The typical *Lithostrotion*-structure may be defined as follows:—

- (1) Well-spaced, alternate septa, all of which extend to the wall; all the septa are of nearly-equal thickness, and each septum varies very little in thickness along its length.
- (2) An external vesicular area in a horizontal section. This area forms a ring, of uniform width, within the wall; it is radiated by both series of septa, and the interseptal spaces are each occupied by one or more vesicles; the inner boundary forms the inner wall of the corallite.
- (3) The tabulæ are conical or gently dome-shaped, without any definite fossular depression; the septa extend inwards, for a greater or less distance, along the upper faces of the tabulæ.
- (4) From the centre of each tabula, an erect, laterally-compressed columella projects upward, and usually reaches the tabula immediately above.

The following are the most important structural modifications:—

#### (1) Diphyphyllidan modification.

The columella is either absent, or does not stretch from tabula to tabula. This type of structure is always associated with very broad, flattened tabulæ. It is common in the group of *Lithostrotion Martini*, but is extremely rare in *L. irregulare* and throughout the *Nematophyllum*-section.

In this modification, the septa stop well short of the centre.

#### (2) Koninckophyllidan modification (compare the structure of *Koninckophyllum* $\theta$ , Pl. XXIII, fig. 4).

The external vesicular area is very broad, and the interseptal spaces are crowded with small vesicles. *Lithostrotion affine* and the whole *Nematophyllum*-section are examples of this type of structure.

#### (3) Clisiophyllidan modification. (Pl. XXIII, fig. 5.)

In a horizontal section, the central area shows the characteristic spider-web structure. This type of structure results from the shape of the tabulæ, which are strongly conical and radiated by a regular series of lamellæ.

The figure illustrates a *Lithostrotion* characteristic of the *Dibunophyllum*-Zone; this form resembles *L. irregulare* in its external characters.

*L. irregulare* and the members of the group of *L. Portlocki* show a simple type of Clisiophyllid-structure. In a horizontal-section of any of these forms, a few of the larger septa are seen to extend to the thick columella, and they are crossed, in the central area, by two or three tabular intersections.

#### (4) Lonsdalia-like modification.

The septa are inconspicuous near the wall, and there is a peripheral area which is almost entirely vesicular.

This type of structure is often partly developed in the typical *Lithostrotion Portlocki*, but is especially characteristic of its variety, *L. ensifer*, in which the walls themselves are feebly developed.

### Notes on the Species recorded in the Stratigraphical Portion of this Paper.

#### The Siphonodendron-Section.

Corallites cylindrical; growth dendroid.

#### LITHOSTROTION MARTINI, Edwards & Haime.

Here I include :—

*Lithostrotion Martini*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 197 & pl. xl, figs. 2-2g.

*L. Phillipsi*, Edwards & Haime, *ibid.* p. 201 & pl. xxxix, figs. 3-3a.

*Diphyphyllum lateseptatum*, McCoy, 'Brit. Palæoz. Foss.' 1851, p. 88 & pl. iii c, figs. 10-10b.

The principal characters are as follows :—

- (1) The presence (except in *D. lateseptatum*) of a distinct columella, not specially thickened.
- (2) Broad, nearly-flat tabulæ.
- (3) The larger septa fall short of the columella, leaving a free space round it.
- (4) A small number of vesicles occurs in each interseptal space of the external area.

There is great variation in :—

- (1) The diameter of the corallite, which varies, in specimens occurring at the same horizon, from 6 to 11 millimetres.
- (2) The grouping of the corallites.—The same mass is often, in parts, extremely flexuous and coalescent (when it is usually named *Lithostrotion Phillipsi*); while, in other parts, the corallites are almost parallel.
- (3) The number of vesicles in the interseptal spaces of the external area.—This depends, mainly, upon the size of the corallites; a radial row of three or four vesicles may be regarded as the usual type, but in the smaller forms this number may be reduced to one only.

**LITHOSTROTION IRREGULARE (Phill.).**

Here I include :—

*Lithostrotion irregulare*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 198 & pl. xli, figs. 1-1 *e*.

*Petalaxis Portlocki*, Edwards & Haime, *ibid.* p. 204 & pl. xxxviii, figs. 4-4 *a*.

I include the last-named coral, on the evidence of specimens which appear to be merely forms wherein the corallites of *Lithostrotion irregulare* are very closely packed.

Since it is customary to refer any narrow dendroid *Lithostrotion* to this species, and since no horizontal section has been figured by Edwards & Haime, I append the following detailed account of the structure which I connote by the specific name :—

- (1) The corallites are narrow and closely packed, in parallel grouping.
- (2) In a horizontal section, the two walls are usually in contact, but when they are separate, the space between them is only divided up by the two series of septa.
- (3) In a horizontal section, a certain number of the larger septa extend to the columella, and the columella is usually continuous, in the direction of its length, with two of the larger septa, so that the section appears to be bisected.
- (4) The tabulæ are close-set and conical, so that, in a horizontal section, the central area exhibits a simple Clisiophyllid-structure.

**LITHOSTROTION JUNCEUM (Flem.).**

As interpreted by Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 196 & pl. xl, figs. 1-1 *b*.

**The Nematophyllum-Section.**

Corallites prismatic, forming a compact mass.

**LITHOSTROTION BASALTIFORME (Phill.).**

As interpreted by Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 190 & pl. xxxviii, figs. 3-3 *b*.

A very common Bristol variety is described in Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 106-108.

**The Group of LITHOSTROTION PORTLOCKI (Bronn).**

Here I include :—

*Lithostrotion Portlocki*, Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 194 & pl. xlii, figs. 1-1 *g*.

*L. ensifer*, Edwards & Haime, *ibid.* p. 193 & pl. xxxviii, figs. 2-2 *a*.

*L. M'Coyanum*, Edwards & Haime, *ibid.* p. 195 & pl. xlii, figs. 2-2 *b*.

For descriptions, see Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 108-10.

The typical member of this group, *Lithostrotion Portlocki* (Bronn), Edwards & Haime, differs from *L. basaltiforme* in (1) its smaller size: (2) its very strong columella; and (3) the common tendency to Clisiophyllidan and *Lonsdalia*-modifications.

#### Mutations of *Lithostrotion*.

Nothing can be stated with certainty concerning the evolution of this group. The earliest form with which I am acquainted occurs near the top of the *Syringothyris*-Zone; it resembles *Lithostrotion irregulare* in its smaller size, in the strength of its columella, in the fewness of the septa, and in the conical tabulæ, but the inner and outer walls are never coalescent, and the septa do not extend to the columella; it also differs in its ramulose manner of growth.

The commonest forms of the two sections that are found in the *Seminula*-Zone are *Lithostrotion Martini* and *L. basaltiforme*. *L. affine* and *L. aff. Portlocki* make their appearance in  $S_2$ .

The *Dibunophyllum*-Zone is characterized by both Koninckophyllidan and Clisiophyllidan modifications of the *Siphonodendron*-section, and by both Clisiophyllidan and *Lonsdalia*-like modifications of the *Nematophyllum*-section, as represented by members of the group of *Lithostrotion Portlocki*.

#### The Clisiophyllids.

In order to explain the terms employed in the explanatory notes which follow, it is necessary to describe, in detail, the horizontal section of a typical Clisiophyllid.

Such a section exhibits four areas: central, medial, external, and peripheral.

The central area is occupied by a system of curvilinear intersections, the fundamental plan of their arrangement being that of a spider's web.

The medial area is radiated only by the primary septa, and has few dissepiments in the interseptal spaces.

The external area is radiated by the primary septa and, usually, by a less-developed secondary series. The interseptal spaces are crowded with dissepiments which, by their closer approximation at the inner margin of the area, form the inner wall.

The peripheral area, at its inner boundary, usually merges, quite insensibly, into the external area; it is distinguished by the predominance of vesicular over radial structure.

#### Septa:—

The primary septa are, usually, very thin and inconspicuous in the peripheral area, but much thicker in the external and medial areas, the maximum thickness being attained at about the inner wall.

The secondary septa are always very thin, and seldom extend inwards as far as the inner wall; they are often practically absent, or but partly developed.

The various genera of this family which have been created by Thomson, Thomson & Nicholson, and Thomson & Duncan, are described and illustrated in Proc. Phil. Soc. Glasgow, vol. xiv (1883) pp. 296–502, pls. i–xiv.<sup>1</sup>

<sup>1</sup> This paper is a summary of numerous earlier papers which appeared in the same Proceedings.



These genera may be grouped in sections, as follows :—

### SECTION I. (The *Koninckophyllum*-Group.)

This group is composed of Clisiophyllids in which the central area contains a thickened mesial plate, surrounded by a very simple network of few meshes.

Here *Koninckophyllum*, *Axophyllum*, and *Acrophyllum* may, for the present, be placed together.

*KONINCKOPHYLLUM*, Nich. & Thoms., may be regarded as having close affinity to *Lithostrotion*, combined with a Clisiophyllidan tendency.

The affinity to *Lithostrotion* is shown in :—

- (1) The lath-like columella, and the simplicity of the structure of the central area.
- (2) The markedly-alternate septa; the two series are of almost-equal strength, and each septum is nearly uniform in thickness throughout its length.
- (3) The secondary septa reach almost, or quite, to the inner wall.

The Clisiophyllidan tendency is conspicuous in :—

- (1) The very broad external area, closely packed with vesicles.
- (2) An extremely-simple type of Clisiophyllid-structure in the central area.

*AXOPHYLLUM* (Edwards & Haime), Thomson.

This genus has apparent resemblance both to *Koninckophyllum* and to *Lonsdalia*, but its true affinity is to the latter.

It resembles *Lonsdalia* in :—

- (1) The highly-specialized Clisiophyllid-structure of the external area. (See under *Dibunophyllum*  $\psi$ , p. 284.)
- (2) The development of a purely-vesicular peripheral area.

It apparently resembles *Koninckophyllum* in having a thick columella, surrounded by a very simple network; but, in the only form from the Bristol area that I include under this genus, the columella, when examined under the microscope, is seen to be complex in structure and to contain, in itself, the probable representative of the entire central area of a *Lonsdalia*. Hence, the true place of this genus is probably in Section V (p. 286.)

*ACROPHYLLUM*, Nich. & Thoms.

This genus I propose to omit, at least for my present purpose.

Those species which only differ from *Koninckophyllum* in the greater extension of the mesial plate across the central area, may well be placed in the genus *Koninckophyllum*; while those species, in which the external and peripheral areas exhibit a highly-specialized Clisiophyllid-structure, may be included in the genus *Axophyllum*.

This separation will also be in accord with the periods at which the two divisions of *Acrophyllum* attained their maximum development; for *Koninckophyllum* has its maximum in  $D_1$ , whereas *Axophyllum* is confined to  $D_2$ .

## Examples from the Bristol Area.

**Koninckophyllum.**KONINCKOPHYLLUM  $\theta$ . (Pl. XXIII, fig. 4.)

The form is conical and elongate.

The calyx is deep, and has a helmet-shaped boss projecting from its floor. A thick mesial plate forms the crest of the boss, and continues, as a lamella, towards the fossula. The sides of the boss are smooth, except for one or two inconspicuous lamellæ.

The horizontal section well exhibits all the characters of the genus, already explained.

**Axophyllum.**AXOPHYLLUM  $\theta$ . (Pl. XXIV, fig. 4.)

The form is short, broad, and turbinate.

The calyx is deep, and has a prominent, laterally-compressed, solid style projecting from its floor.

The horizontal section exhibits the highly-specialized characters of the genus, as already explained.

Microscopic examination reveals the essentially-complex nature of the solid columella, as above stated.

SECTION II. (The **Dibunophyllum**-Group.)

This section comprises the most typical members of the family, in which the central area is strongly developed and exhibits a thickened mesial plate and well-marked lamellæ.

Here I include *Dibunophyllum*, *Clisiophyllum*, *Aspidophyllum*, and, tentatively only, *Carcinophyllum*.

Thomson points out the following distinctions between the three first-mentioned genera:—

(a) In horizontal sections.

In *Dibunophyllum*, Nich. & Thoms., the mesial plate stretches completely across the central area.

In *Clisiophyllum* (Dana), Thomson, the mesial plate crosses the centre, but does not extend to the circumference of the central area on either side.

In *Aspidophyllum*, Thomson, the mesial plate is only conspicuous, between the centre and the circumference of the central area, on the fossular side.

(b) These distinctions correspond to the following differences in the nature of the calicinal boss:—

In *Dibunophyllum*, the boss is elongate and dome-shaped, with a long crest.

In *Clisiophyllum*, the boss is conical, with a very short crest.

In *Aspidophyllum*, the boss is shaped and crested like a fireman's helmet.

For the present, I shall include *Aspidophyllum* as a subgenus of *Dibunophyllum*, for two reasons:—

(1) There appears to me to be no essential difference between the horizontal sections of *Aspidophyllum*, as shown in pl. xiii, figs. 7 & 8, Proc. Phil. Soc.

Glasgow, vol. xiv (1883), and the sections of *Dibunophyllum*, shown in pl. xii, fig. 1, *ibid*.

(2) The helmet-shaped boss is a phenomenon common to all crested Clisiophyllids; it depends upon the fact that a more prominent lamella runs down the tent-shaped tabulæ, from one end of the crest into the fossula, whereas the other end of the crest usually is sharply terminated and not continuous with a strong lamella (compare *Koninekophyllum*  $\theta$ , p. 282).

The distinction between *Dibunophyllum* and *Clisiophyllum* seems to be of more practical utility.

*Clisiophyllum* includes all the Clisiophyllids of this section, in which the mesial plate is wholly included within the central area; and in which the radial lamellæ are all thin and of similar character, so that the area presents a radial, rather than an axial symmetry.

*Dibunophyllum* includes all the Clisiophyllids of this section, in which the thickened mesial plate extends nearly across the central area, and is continued, as a more prominent lamella, into the fossula.

The distinction is, however, obviously only one of degree.

### Examples from the Bristol Area.

#### *Dibunophyllum*.

##### DIBUNOPHYLLUM $\theta$ . (Pl. XXIV, fig. 1.)

The form is cylindrical.

Horizontal section.—The central area is composed of open vesicles, and is bisected by a distinct, continuous plate, which is nowhere greatly thickened.

The primary septa, 40 to 50 in number, are well-spaced, not specially thickened, and distinctly traceable, almost to the outer wall. The secondary septa are either absent or inconspicuous, extending only a short distance inwards from the outer wall.

The septal break ('fossula') is well marked, and the prolongation of the mesial plate projects into it.

The external area is loosely vesicular, without a well-defined inner wall.

Resemblances and differences.—The following horizontal sections, figured by Thomson (Proc. Phil. Soc. Glasgow, vol. xiv, 1883), bear considerable resemblance to the Bristol form:—

*Clisiophyllum coniseptum* (Keyserling), Thomson, pl. xiii, fig. 4. [In the Explanation of the Plate, it is called *Clisiophyllum Danai*, Thomson.]

Here, however, only a small central portion of the mesial plate is specially thickened; but axial symmetry is suggested.

*Histiophyllum Dicki*, Thomson, pl. xii, fig. 6.

Here, axial symmetry is suggested by the more prominent lamella, which extends into the fossula, but there is no specially-thickened mesial plate crossing the centre. [The genus *Histiophyllum* may be, perhaps, better placed in Section III.]

*Dibunophyllum* sp., Thomson, pl. xii, fig. 3.

Here the central area is reduced, and the inner wall more strongly marked than in our species. This may be regarded as an intermediate stage between *Dibunophyllum*  $\theta$  and *Dibunophyllum*  $\psi$ .

**DIBUNOPHYLLUM  $\phi$ .** (Pl. XXIV, fig. 1 a.)

Proc. Bristol Nat. Soc. n. s. vol. x (1903) pl. i, fig. 6 (*Clisiophyllum turbinatum*).

The form is cylindrical, of small cross-section. It may be regarded as a variant of *Dibunophyllum*  $\theta$ ; it differs in the narrowness of the external area and, usually, in the presence of a secondary series of short, thick septa.

*Clisiophyllum oblongum*, Thomson, Proc. Phil. Soc. Glasgow, vol. xiv (1883) pl. xiii, fig. 2, appears to be a true *Dibunophyllum*, and to be closely related to our form.

**DIBUNOPHYLLUM  $\psi$ .** (Pl. XXIV, figs. 2 & 2 a.)

This is a typical representative of the most highly-specialized members of this section. The form is short and conical. The calicinal boss has the typical characters of the genus.

Horizontal section.—The central area has a well-defined boundary, which projects, as a cusp, into the fossular gap. The mesial plate is strongly developed, and continued into the fossular gap.

The primary septa taper at both ends. The secondary septa are not prominent, although usually developed in a part, at least, of the external area.

The external area is crowded with vesicles and bounded by a well-marked inner wall, which is formed by the very close approximation of two or three rings of vesicles. The peripheral area is only partly developed.

Resemblances and differences.—*Clisiophyllum turbinatum*, M'Coy, 'Brit. Palæoz. Foss.' 1851, pp. 88 & 96, figs. a, b, c, appears to be a true *Dibunophyllum*, but to differ from our species in the ratios of the areas and in a larger conical angle.

*Clisiophyllum turbinatum* (M'Coy), Edwards & Haime, appears to include our form, as well as other conical *Clisiophyllids* which I regard as essentially distinct. From Nunney, near Frome (included in the list of localities from which the specimens, examined by Edwards & Haime, are derived), I only know a short, conical *Clisiophyllid* which differs entirely from *Dibunophyllum*  $\psi$  in having a Zaphrentid-type of structure (see below).

*Clisiophyllum turbinatum* (M'Coy), Thomson, Proc. Phil. Soc. Glasgow, vol. xiii (1882) p. 537 & pl. vi, fig. 6, differs considerably from our form:—

- (1) Though a mesial crest is mentioned in the description, there seems to be no trace of a mesial plate in the figure.
- (2) The inner wall in Thomson's figure is not nearly so strongly developed as in our form.

The following figures of horizontal sections, given in Thomson's paper, Proc. Phil. Soc. Glasgow, vol. xiv (1883), seem to denote species closely related to our form:—

*Dibunophyllum M'Chesneyi*, Nich. & Thoms., pl. xii, figs. 2-2 b.

*Aspidophyllum obovatum*, Thoms., pl. xiii, fig. 7.

*Aspidophyllum Konincki*, Thoms., pl. xiii, fig. 8.

### 'Clisiophyllum.'

'CLISIOPHYLLUM' (CARCINOPHYLLUM)  $\theta$ . (Pl. XXIV, figs. 3-3 b.)

This species cannot be regarded as, in any sense, a typical member of the genus *Clisiophyllum*; it is only placed here tentatively, until its real affinities are better understood.

Form: conical, usually elongated, and often curved.

Epitheca: strongly rugose and, in specimens from D<sub>1</sub>, usually with hollow 'roots.'

Horizontal Section.—Central area marked out by a strongly-defined oval boundary.

Mesial plate short, and entirely surrounded by a network of anastomosing intersections. Lamellæ almost as numerous as the primary septa. The mesial plate and lamellæ are, however, often indistinct.

Primary septa, usually 33 in number, well spaced, thick, and not extending as far as the outer wall. Secondary septa short and stout, projecting inwards from the thick inner wall.

Fossula: there is scarcely a suggestion of septal break.

Peripheral area: narrow, but composed of large vesicles, and not radiated by prolongations of the septa. The loose texture of the peripheral area renders it peculiarly liable to destruction, a fact which affords an easy method of recognizing weathered specimens. In its structural details, this species presents a general resemblance both to *Lonsdalia* and to *Campophyllum* aff. *Murchisoni*; the resemblance to the former is, however, doubtless deceptive, whereas the resemblance to the latter is probably owing to true affinity (see below, p. 287).

The only previously-described form to which '*Clisiophyllum*'  $\theta$  appears to be closely related is *Carcinophyllum Kirsopianum*, Thoms., Proc. Phil. Soc. Glasgow, vol. xiv (1883) pl. xii, fig. 9 a. This species agrees in all essential characters with our form, but has no mesial plate. Since, however, the mesial plate is not distinguishable, in certain sections which I have had cut from undoubted specimens of our coral, the reference of our species to *Carcinophyllum* seems justified.

### SECTION III. (The *Cymatiophyllum*-Group).

Clisiophyllids which resemble the *Dibunophyllum*-group in all characters, except the special thickening of the mesial plate. The boss has consequently no crest, but is gently rounded, flattened or slightly depressed on the top.

Here I include *Centrophyllum*, *Rhodophyllum*, *Cymatiophyllum*, and *Albertia*, all of them genera established by Thomson.

It will be unnecessary, in this place, to discuss the value of the distinctions which Thomson draws between the above genera, since no examples have as yet been found, in the area with which I am dealing, that can be definitely assigned to this section.

#### SECTION IV. (The *Aulophyllum*-Group).

Clisiophyllids, the central area of which is very sharply defined by a circular wall, projecting, as a cusp, into the fossular gap. The central area is composed of a network of vesicles, which are very minute round the circumference, but larger in the centre. The boss is a cratered cone.

I have not seen sufficient material to judge of the value of the separation of *Cyclophyllum*, Dana & Thoms., from *Aulophyllum*, Edwards & Haime. The only form with which I am personally acquainted from this area, seems to be identical with *Cyclophyllum pachyendothecum*, Thomson, Proc. Phil. Soc. Glasgow, vol. xiv (1883) p. 493 & pl. xiv, fig. 1.

#### SECTION V. (The *Lonsdalia*-Group).

Clisiophyllids with a sharply bounded central area, a strong inner wall, a narrow external area, and a strongly-developed peripheral area, composed of large vesicles.

This group probably includes *Axophyllum* as well as *Lonsdalia* (see above, p. 281).

#### Examples from the Bristol Area.

##### *Lonsdalia*.

##### *LONSDALIA FLORIFORMIS* (Flem.).

As interpreted in Edwards & Haime, 'Monogr. Brit. Foss. Cor.' pt. iii (1852) p. 205 & pl. xliii, figs. 1-2.

A dendroid variant of this type, resembling, externally, *Lonsdalia rugosa*, M'Coy, is very common in the Bristol area.

*LONSDALIA RUGOSA*, M'Coy, 'Brit. Palæoz. Foss.' 1851, p. 105 & pl. 3B, figs. 6-6c.

Typical examples are common in D<sub>2</sub> of the Avon section.

#### Notes on the Evolutionary History of the Clisiophyllids, as developed in the Bristol and Neighbouring Areas.

The earliest occurrence of the Clisiophyllids is in the *Syringothyris*-Zone of the Mendips and Tenby. These forms probably belong to a single species, which exhibits the following characters:—

- (1) The tabulæ in the central space are vaulted up into tall, laterally-compressed cones, regularly radiated by lamellæ, and more or less conspicuously crested.
- (2) The primary septa are stout, and of nearly-uniform thickness throughout; the secondary septa are short and stout.
- (3) A thick outer wall is formed by the thickening of the ends of the septa.

The nature of the outer wall and its relation to the septa are points of strong resemblance to *Zaphrentis*, while the arching of the tabulæ suggests a *Zaphrentis*-like ancestor.

It has already been suggested, in considering the evolution of *Lithostrotion*, that, at the top of the *Seminula*-Zone and in the succeeding *Dibunophyllum*-Zone, *Lithostrotion* came under a general Clisiophyllidan influence and gave rise, in one direction to the *Koninckophylla*, and, in the other, to the *Dibunophylla*.

Of the *Dibunophylla*, the earlier examples, namely, *Dibunophyllum*  $\theta$  and *D.*  $\phi$  (the maxima of which occur in  $D_1$ ), exhibit a comparatively-simple type of structure. On the other hand, *Dibunophyllum*  $\psi$ , *Lonsdalia floriformis*, and *Axophyllum*  $\theta$ , all of which only attain their maximum in  $D_2$ , exhibit the most highly-specialized type of Clisiophyllid-structure. The great development of the vesicular peripheral zone in such a form as *Lonsdalia floriformis* would also suggest the approach to the end of a line of evolution.

'*Clisiophyllum*' (*Carcinophyllum*)  $\theta$ , which reaches its maximum at the top of  $S_2$  and the base of  $D_1$ , presents a problem to which there is as yet no solution. The well-developed peripheral zone and the excrescence of 'roots' in specimens from  $D_1$ , would suggest that this form occurs there at the end of a line of evolution, rather than at the beginning or in the middle of such a line.

Whatever may have been its origin, it seems most probable that both this form and *Campophyllum* aff. *Murchisoni* (Proc. Bristol Nat. Soc. n. s. vol. x, 1903, pl. i, fig. 5) had a common ancestry.

## (2) NOTES ON THE BRACHIOPODS.

### Productus.

*PRODUCTUS BASSUS*, sp. nov. (Pl. XXV, figs. 1 & 1 a.)

Compare James Hall, 'Eleventh Annual Report of the State Geologist New York, 1891 (1892) 'Introductio to the Study of Brachiopoda' pt. i: *Productella costatula*, Hall, p. 228 & pl. xxi, figs. 15-17; and *Productella hystriacula*, Hall, pl. xxi, fig. 21.

**Description.**—Form: that of a small specimen of *Productus* cf. *Martini* (see below, p. 288).

The convex valve is composed, in the neighbourhood of the beak, of concentric bands which often imbricate; the ribs are short and discontinuous near the beak, but become continuous over the anterior portion of the valve; there are well-marked wrinkles on the shoulders; the spines are short, but very abundant; not only do they form the terminations of the short discontinuous ribs in the beak-region, but they also project from the continuous ribs on the anterior portion, usually in concentric rows.

**Resemblances.**—So close is the general resemblance of *Productus bassus* to Hall's species (cited above) from the Chemung Group, that it seems highly probable that *Pr. bassus* also belongs to the subgenus *Productella*; I have, however, failed to find any trace of area or teeth in our specimens.

The only well-known species of Carboniferous brachiopoda to which *Productus bassus* bears any appreciable resemblance is *Pr. aculeatus* (cf. Davidson, 'Monogr. Brit. Foss. Brach.' vol. ii, 1858-63, Pal. Soc. p. 166 & pl. xxxiii, figs. 18-19).

*PRODUCTUS* cf. *MARTINI* (Sow.). (Pl. XXV, figs. 2 & 2a.)

**Convex valve.**—The general form is approximately that of the specimen figured by Davidson *op. cit.* pl. xliii, figs. 2a & 2b, under the name of *Productus semireticulatus*, but the valve is more elongate than in those figures, although never geniculate. The sides and medial area are remarkably flattened, so that a section through the hinge-line intersects the valve in a rectangle. There is seldom a distinct sinus. The ribbing varies from striate (when the surface appears nearly smooth) to close and thread-like (as in our figure). The spines are few and scattered. Semireticulation is usually well-marked.

**Concave valve.**—This valve is truly geniculate, the beak-region being almost perfectly square and flat. Concentric wrinkles extend over the whole of the flat surface of the valve.

**Size.**—The concave valve is usually less than 25 millimetres square.

**Discussion.**—The type-form of *Productus Martini* (Sow.), as figured in 'Mineral Conchology' vol. iv (1823) pl. cccxvii, figs. 2-4, and as represented in Davidson *op. cit.* pl. xliii, figs. 7 & 7a, resembles *Productus* cf. *Martini* in its:—(1) square cross-section; (2) elongate form; (3) semireticulate ornament; (4) small number of spines. But Sowerby's type differs very considerably from our form in (1) the marked geniculation of the convex valve; and (2) the skirt-like extension of the convex valve.

Since I have not met with Sowerby's form in the Bristol area, I do not know whether *Productus* cf. *Martini* is genetically related to the typical *Pr. Martini* (Sow.). If both forms occur on a continuous evolutionary line, the abnormal development of shell in Sowerby's type would suggest that the true *Pr. Martini* represents a late stage, whereas *Pr. cf. Martini* is certainly an early stage.

**Differences.**—The square-cut sides and rectangular section, as well as the much smaller form, distinguish this species from a typical *Productus semireticulatus*.

**Variety.**—Certain specimens from  $Z_1$  have coarser ribbing and a distinct sinus, with a few symmetrically-placed large spines. This variety resembles *Pr. longispinus*, but it differs from that species in its more considerable size, and in the fact that the median section is always more rounded in the neighbourhood of the beak.

**Mutation.**—The evolution of *Productus semireticulatus* from this form takes place during  $Z_2$ , and is almost insensible. There can, therefore, be no hesitation in assigning *Pr. cf. Martini* to the gens of *Pr. semireticulatus*; but, since the typical *Pr. semireticulatus* is only found above  $Z_2$ , whereas the semireticulate *Producti*, found below that zone, belong almost exclusively to the *Pr. cf. Martini* section, it is useful to maintain the separate sections.



*PRODUCTUS SEMIRETICULATUS* (Martin), as interpreted in Davidson's 'Monogr. Brit. Foss. Brach.' vol. ii (1858-63) Pl. Soc. pl. xliii, fig. 1.

The characters of chief importance are:—The broad form; the sulcate or flattened medial area; flattened wings; strong semi-reticulation.

The adductors in the convex valve are attached more anteriorly than is the case in the giganteid *Producti* (see below, p. 293).

Evolution and mutation.—As already suggested, the typical *Productus semireticulatus* was probably evolved from forms closely allied to *Pr. cf. Martini* during the period represented by  $Z_2$ .

The typical form reaches its maximum at  $\gamma$  and in the lowest part of  $C_1$ . Near the top of  $S_1$ , the gens is represented by a mutation with very long and numerous spines: this mutation has given rise to the title of '*longispinus-bed*' for certain shales and thin limestones which occur near the top of  $S_1$ , in the Great Quarry, Clifton, Avon section; the shales are crowded with the spines and tests of this mutation. With this spinous mutation, we appear to have reached the end of a line of evolution, for no examples of semireticulate *Producti* are again met with in the Bristol or surrounding areas, until the occurrence of *Pr. scabriculus* in Horizon  $e$ , at the very top of the Carboniferous-Limestone Series.

[Very common in the Mendip area,<sup>1</sup> and especially characteristic of  $C$ , is a form similar to *Productus semireticulatus* var. *concinus* (Sow.), as represented in Davidson's 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xliii, figs. 9 & 10. This form may, with great probability, be also traced back to *Productus* cf. *Martini* and, apparently, represents a divergent line of evolution, characterized by the gradual accession of a geniculate form and a coarser type of ornament.]

#### *PRODUCTUS* $\theta$ . (Pl. XXV, fig. 3.)

General characters.—Hinge-line not exceeding the width of the shell. Shell large, often very large. Test thick, so that the pattern of the ribbing does not appear on the cast.

Convex valve.—The body of the valve is almost globular, but it contracts rapidly towards the beak; the flanks are steep. The wings are flattened, and strongly marked off from the rest of the valve. The ribbing is fine, but distinct; the spacing of the ribs is maintained almost uniform over the entire valve, owing to the intercalation of two or three fresh series of intermediate ribs. All the individual ribs of each new series start, approximately, at the same distance from the beak. The ribs of each new series are

<sup>1</sup> The evidence upon which these statements are founded rests, largely, upon an examination of the specimens which Mr. T. F. Sibly, B.Sc., has so carefully collected from the Burrington Section (Mendips), in the course of preparing his recently-published paper in the Proceedings of the Bristol Naturalists' Society.

at first thin, but they soon acquire the same thickness as the ribs of the earlier series. The new ribs remain thin, longest, on the flanks. Concentric wrinkles are usually conspicuous on the wings, and are often indistinctly continued on to the beak-region. The ribs are finely crenulated by regularly-spaced annulations. The muscular impressions are of the general type seen in strongly-convex *Producti* (see text-fig. 3 & note below, p. 293).

Resemblances and differences.—This form, which is very common in  $S_1$ , has always been recorded as *Productus giganteus*, on account of its large size, extreme convexity, and fine ribbing (characters which have also been responsible for the registration of *Chonetes* cf. *comoides* under the same name).

*Productus*  $\theta$  differs from *Pr. giganteus* in the flatness of the wings, the shorter hinge-line, the narrower beak, and a distinct trace of semireticulation, and in these characters it shows an approximation to *Pr. semireticulatus*. In association with *Productus*  $\theta$  are found large examples of *Pr. semireticulatus*, which only differ from the former in the flattening of the medial area of the convex valve and, consequently (see below, p. 293), in the more anterior position of the adductor-impressions, as well as in the stronger semireticulation.

In the general type of ribbing, the uniform narrowing of the valve towards the beak, and the steep flanks, *Productus*  $\theta$  resembles *Productus* *Cora* [Dav.], and especially the mutation *C. Productus*  $\theta$  differs, however, in the broad flattened wings and in the thick test.

Evolution.—It seems probable that *Productus*  $\theta$  represents a complex type, formed by evolution from *Pr. Cora* [Dav.] mut. *C*, along a line characterized by strong assimilation to *Productus semireticulatus*.

Discussion.—The great size of the shell and the thick test suggest that *Productus*  $\theta$  is the culminating form of a line of evolution, and this suggestion is somewhat confirmed by the fact that, between the top of  $S_1$  and the top of  $S_2$ , where the true *Productus giganteus* makes its first appearance, large *Producti* are absent in the Bristol area.

I am, however, doubtful whether *Productus*  $\theta$  is more than a rather striking divergent from the gens of *Pr. Cora* [Dav.], for it seems almost impossible to separate the young form of *Productus*  $\theta$  from the mutation of *Pr. Cora* [Dav.], which is figured in Proc. Nat. Soc. Bristol, n. s. vol. x (1903) pl. ii, fig. 4, and occurs at nearly the same horizon. For this reason, it seems better to await more material before creating a new specific name. On the other hand, *Productus*  $\theta$  has an important stratigraphical value, wherefore it is essential, for my present purpose, that it should be described and figured.

*PRODUCTUS CORA*, d'Orb., Davidson. (Pl. XXV, figs. 4-4 b.)

This is a large gens which includes, as a typical member, the form figured in Davidson's 'Monogr. Brit. Foss. Brach.' vol. ii (1858-63) Pal. Soc. pl. xxxvi, figs. 4-4 b. All the following

characters are exhibited, in the same specimen, only by the most typical members of the group:—

Form elongate, narrowing uniformly to the beak, with tall and steep flanks. Beak narrow and strongly arched. Hinge-line short, with short wings or ears. Ribs fine and sharp, with very narrow intermediates. Concentric wrinkles indistinct on the medial area, but becoming deep pleats on the wings. Test thin, so that the cast takes the pattern of the ribbing.

### Mutational Forms.

#### MUTATION C.

Wings usually flattened, with very strong pleats. The ribbing on the flanks is comparable in sharpness and alternation with that of an *Orthotetes*. The form is markedly broad, anteriorly.

This form is very rare in  $Z_1$ ,<sup>1</sup> more common in  $Z_2$ , and abundant in C. It has already been suggested that *Productus*  $\theta$ , which characterizes  $S_1$ , is perhaps merely an aberrant variant of the gens. of *Productus Cora* [Dav.].

#### MUTATION $S_2$ . (Pl. XXV, fig. 4.)

A small form, not specially widened anteriorly. The short, usually-convex ears are strongly wrinkled, but not actually pleated. The ribbing is fine and of the more normal type, as described under *Productus*  $\theta$ . Many specimens show broad, irregular wrinkles over the entire valve.

This form is especially characteristic of  $S_2$ .

Pl. XXV, figs. 4a & 4b illustrate a closely-related form, occurring in  $S_2$  and  $D_1$ , which is remarkable for its extremely-fine ribbing.

Differences.—*Productus Cora* [Dav.] is likely to be confused only with *Pr. hemisphericus*; the differences between the two forms are pointed out in the remarks on the latter species.

Evolution.—The evolution of the gens of *Productus Cora* [Dav.] appears to have been carried out in a distant region, and the early forms found in the Bristol area were probably introduced by migration. This suggestion is rendered probable by (1) the extreme rarity of the earliest members, and (2) the absence in our area of transitional forms, linking them with pre-existing *Producti*.

#### PRODUCTUS HEMISPHERICUS, J. Sow. (Pl. XXV, fig. 5.)

One of the original types is figured in Davidson's 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858–63) pl. xl, figs. 9–9b.

The shell is usually transverse, and the hinge-line does not exceed the width of the shell. The beak is convex, but not strongly arched. The medial area slopes gently into the flanks. The wings are short, and somewhat cylindrically rolled. The ribbing is of the type already described under *Productus*  $\theta$ . Concentric wrinkles are, as a rule, well marked on the wings, but are indistinct across the

<sup>1</sup> The only specimen that I have seen from  $Z_1$  appears to be easily distinguishable.

medial area. A row of short, curved spines projects from the hinge-line of the convex valve.

Differences.—From *Productus Cora* [Dav.] this species is distinguished by the more gradual slope of the sides, the broader and less-arched beak, and the stronger cylindrical rolling of the wings: typical examples are also much more transverse.

From *Productus giganteus* this species differs in its smaller size, in the fact that the wings do not project beyond the rest of the shell, in the greater regularity and distinctness of the ribs, and in their conspicuous increase by intercalation, at definite concentric levels.

Discussion.—Having collected numerous specimens from Mynydd y Gareg (near Kidwelly), the locality from which the types were obtained, and having compared them with specimens from the Bristol area, I am convinced of the absolute identity of the Bristol form with the type. Furthermore, this species abounds at the same horizon (D<sub>1</sub>) throughout the Bristol area as at Kidwelly.

Varieties.—A form, in which the shell is extremely elongated, differs in no other characters, and must be considered as a mere variety.

The figure (Pl. XXV, fig. 5) illustrates a form, from the typical horizon at Sodbury, in which the beak is much narrower and the ribbing much stronger and more distinct than in the type-specimens.

#### PRODUCTUS GIGANTEUS (Martin).

As interpreted in the following figures:—Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pls. xxxvii-xxxviii, & pl. xxxix, figs. 1, 4.

The characters of most importance are:—The produced and cylindrically-rolled wings; the broad beak sloping gradually into the rest of the valve; the irregular intercalation of the ribs, which are commonly flexuous; and finally, the transverse form.

#### PRODUCTUS PUNCTATUS (Martin), Davidson.

Specimens, apparently identical with Davidson's, *op. cit.* pl. xliv, fig. 12, have been found by Mr. T. F. Sibly, in S<sub>2</sub>, in the Weston area; I have also seen a specimen, similar to fig. 9 of the same plate, from Black-Rock Quarry, Tenby (S<sub>2</sub> and D<sub>1</sub>). A scabriculate mutation, which is almost perfectly convex, with a very narrow and strongly-arched beak, is common in D<sub>2</sub> and Horizon e.

#### PRODUCTUS PUSTULOSUS, Phil., Davidson.

This gens seems to exhibit continuous mutation, but I have collected too little material as yet to speak definitely.

A form like Davidson's, *op. cit.* pl. xli, fig. 2, is common in  $\gamma$ , at Burrington Combe, and I have collected variants of this gens from Z<sub>1</sub>, Z<sub>2</sub>,  $\gamma$ , and C.

#### PRODUCTUS SCABRICULUS (Martin), Davidson.

The commonest form in the Bristol area appears to be almost identical with Davidson's, *op. cit.* pl. xlii, figs. 5 & 6, but the semi-reticulation is usually more strongly marked in our specimens.

The median ridge in the interior of the concave valve is grooved, as in fig. 8 *a* of the same plate.

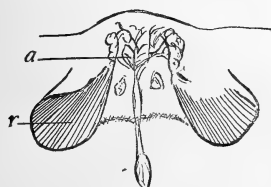
From the coarseness of the ribbing, this may be called the costate form, since the specimens bear a strong resemblance to *Productus costatus*. There is a variety in which the ribbing is very much finer and the semireticulation much clearer; this I term the semireticulate variety.

Specimens occur in *D*<sub>2</sub> and *ε*, but the maximum is in *ε*.

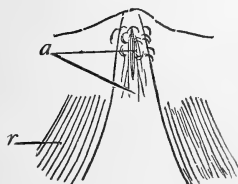
### Note on the Position of the Adductor-Impressions in the Convex Valve.

The strain on the muscle at its point of attachment to the convex valve must be in the direction of the stress caused by contraction, and hence must act along the muscle. This strain will naturally

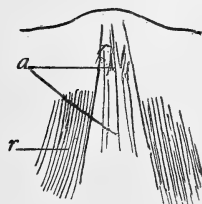
Fig. 3.—Muscular scars in the convex valve.



*Productus* *θ*. *S*<sub>1</sub>.



*Productus Cora* [Dav.]  
Mutation from *S*<sub>1</sub>.



{ *Productus*  
aff. *semireticulatus*.  
*S*<sub>1</sub>.

*a* = Adductors.      *r* = Diductors.

cause displacement of the area of attachment, until the stress is at right angles to that area. Hence, if the valve to which the adductor is attached becomes more convex, there will be a shift of the area of attachment towards the beak: the reverse shift taking place in a flattened or sulcate valve. For this reason, the relative positions of the adductors and diductors is similar in the convex forms *Productus giganteus*, *Pr. Cora*, *Pr. θ*, and *Chonetes comoides*, but differs from that observable in the sulcate forms of *Productus semireticulatus*. The

accompanying diagrams (fig. 3) illustrate this point (see also under *Chonetes* aff. *comoides*, p. 295).

### Chonetes.

CHONETES cf. *HARDRENSIS*, Phil. (Pl. XXVI, figs. 1 & 2.)

I have retained the name *hardrensis*, because it does no more  
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than connote certain characters which are common to a great number of *Chonetes*, without implying genetic relationship. In addition to the generic characters, *Chonetes* cf. *hardrensis* implies small size, slight convexity, and the increase of ribs by forking and intercalation. On the other hand, *Ch. laguessiana*, de Kon., can only be correctly applied to a particular group of the *hardrensis*-circulus, which is characterized by a strongly-transverse shell and very fine ribbing.

The distinction of the forms which occur at different horizons must necessarily depend upon very small differences, but will probably be possible when a very large number of specimens have been collected from each horizon. At present, I am unable to separate definitely from certain Tournaisian forms the specimens which occur in D<sub>2</sub> and ε in the Bristol and surrounding areas.

On the other hand, certain varieties apparently characterize particular zones throughout the Bristol and surrounding areas. For example, a characteristic form (*Chonetes* cf. *laguessiana*) of the Lower Tournaisian (K and Z<sub>1</sub>) has a flattened, strongly-transverse, rectangular shell and very fine, close striæ. Compare Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xlvii, fig. 19; but usually the form is nearly as large as fig. 19 b.

Davidson, *op. cit.* pl. xlvii, fig. 13, gives the form, and in fig. 12 c the manner of ribbing, characteristic of that mutation which is abundant at the top of the Tournaisian (C); in this form the shell is nearly semicircular, and moderately convex.

CHONETES cf. CRASSISTRIA (M'Coy) and CHONETES 'BUCHIANA,' Dav. (? de Kon.), Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xlvii, figs. 17, 28 & pl. lv, fig. 12.

I am far from satisfied that the shell, which is so characteristic of K<sub>1</sub> in the Bristol area, has been correctly referred to *Chonetes Buchiana*, de Kon., by Davidson. The concentric, erect lamination, so characteristic of the Bristol form, appears to be entirely absent from the type of de Koninck's species.

*Chonetes* cf. *crassistria* is employed in the text, to cover small *Chonetes* with coarse ribbing which forks on the *hardrensis*-plan. There is a complete transition between these forms and *Chonetes* 'Buchiana', Dav. The ribs in a typical example of *Chonetes* cf. *crassistria* often exhibit the transverse, erect scales which characterize *Ch. cf. Buchiana*; and, by a diminution in forking, *Ch. cf. crassistria* passes imperceptibly into *Ch. cf. Buchiana*.

CHONETES PAPILIONACEA, Phil., and CHONETES cf. COMOIDES (J. Sow.). (Pl. XXVI, fig. 3.)

Compare Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xlvii, figs. 3-5.

*Chonetes papilionacea* denotes finely-ribbed, flattened forms, with a thin shell. The pits in the under layer of the test are small, circular, and adjacent.

*Chonetes* aff. *papilionacea* denotes the group of early papilionaceans; it comprises large forms, in which one valve is markedly convex, and the pits are elongated and well-spaced.

It seems probable that *Chonetes Dalmaniana*, de Kon. (Davidson, *op. cit.* pl. xlv, fig. 7), is the link between the Tournaisian forms of *Ch. cf. hardrensis* and the present group: for, where this form is abundant, *Ch. cf. hardrensis* becomes rare, and the convex early papilionaceans make their first appearance.

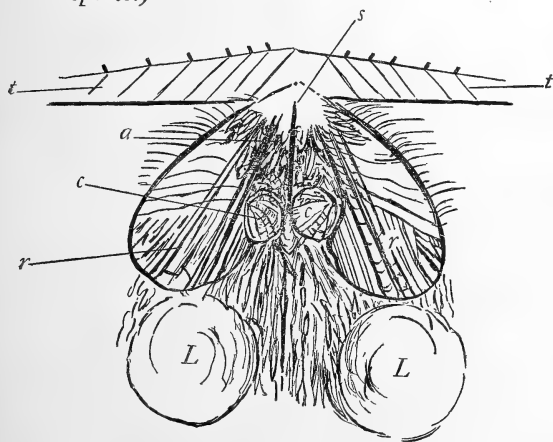
In some localities the convexity of the early papilionaceans is so great that the shells may easily be mistaken, at first sight, for *Productus giganteus*. This form I have denoted by *Chonetes cf. comoides*, as I am unacquainted with the internal characters.

CHONETES aff. COMOIDES (J. Sow.). (Pl. XXVI, fig. 4 & text-fig. 4.)

Compare Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. lv, figs. 6-8.

This is a thick-shelled papilionacean of considerable convexity, characteristic, so far

Fig. 4.—Interior of a convex valve of *Chonetes* aff. *comoides*. (The teeth are omitted, and the area is worn down, so that it shows the tubuli, which communicate with the bases of the spines.)



a = Adductors.

c = Auxiliary adductors.

s = Medial septum.

r = Diductors.

L = Depressions.

as I know, only of the *Dibunophyllum*-Zone and the Upper *Seminula*-Zone, where it is associated with *Productus giganteus*.

In area, teeth, and the row of spines along the cardinal ridge, it is a typical *Chonetes*, but the muscular impressions are practically identical with those of *Pr. giganteus*.

From *Ch. comoides* our form differs only in less convexity at the beak, and

in the presence of distinct tubuli, which run obliquely through the shell, under the area, and communicate with the bases of the spines on the cardinal ridge. It is a remarkable instance of the approximation of characters in cognate forms, existing at the same time, that, while *Chonetes* aff. *comoides* simulates *Productus giganteus* in all its characters (except area and teeth), it is not unusual to find

examples of *Productus giganteus* at the same level, which have developed a narrow hinge-area and show distinct traces of tubuli, beneath the area, in communication with a series of spines along the cardinal ridge (*Chonetiproductus*).

### Leptena.

#### LEPTENA ANALOGA (Phil.).

As interpreted in Davidson's 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xxviii, figs. 1-3 (*Strophomena analoga*).

### Orthotetes.

#### ORTHOTETES CRENISTRIA (Phil.).

As interpreted in Davidson's 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pls. xxvi & xxvii (*Streptorhynchus crenistria*).

The forms of this large gens undergo continuous modification, and consequently specimens found at two horizons, separated by a considerable vertical interval, are conspicuously distinct. To this gens, at least throughout the areas which I have myself examined, the labour-saving formula—'there are no greater differences between the different varieties than could be found between individuals occurring in the same bed'—most assuredly does not apply. The individuals seen in a particular bed are usually exact duplicates of one another, and, all alike, differ from the forms occurring in an earlier or later zone.

Without increasing very considerably the number of plates, it is impossible to give a satisfactory account of the mutations of the gens; I shall consequently content myself with the description of two striking mutations only.

MUTATION Z characterizes the *Zaphrentis*-zone, and especially  $Z_2$ .

The brachial valve is globose; the hinge-area is broad and *Streptorhynchus*-like; the hinge-line is usually produced into short ears; the ribs are close-set, and the alternation of ribs is made out with difficulty.

The convexity of the brachial valve and the type of ribbing make it often difficult to distinguish this form from *Schizophoria resupinata*, with which it is found associated. This is another instance of the approximation of co-existing cognate forms.

MUTATION C. Characteristic of the *laminosa*-subzone.

This mutation is typically *Strophomena*-like. The brachial valve is convex, the hinge-area narrow, and the alternation of ribs very distinct. There is often a medial depression in the brachial valve (cf. *Orthotetes crenistria*, var. *Kellii*, M'Coy).

### Schizophoria.

#### SCHIZOPHORIA RESUPINATA (Martin), Davidson.

Davidson, in his 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xxix, figs. 1 & 2 (*Orthis resupinata*), represents the form<sup>1</sup>; but

<sup>1</sup> The Bristol forms, common in  $Z_2$ , have, however, a much deeper brachial valve.



the dimensions of the Bristol specimens are considerably less than those of Davidson's figures.

### Rhipidomella.

*RHIPIDOMELLA MICHELINI* (L'Éveillé), Davidson.

Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xxx, figs. 6-8 (*Orthis Michelini*).

[A species of *Rhipidomella*, with strongly-marked beak and hinge-area, which bears a strong resemblance to *Rh. Michelini*, occurs very rarely in  $\epsilon$ .]

### Cliothyris.

*CLIOTHYRIS ROYSSII* (L'Éveillé).

Fig. 8, Davidson, *op. cit.* pl. xviii (*Athyris Royssii*), represents the typical form and ornament.

*Cliothyris Royssii* mut.  $\beta$  is described and figured in Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 124 & pl. ii, fig. 2.

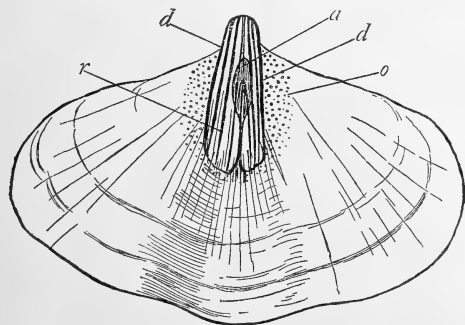
This mutation is a more globose shell, usually of smaller size, with a broader beak and a larger perforation. It occurs most abundantly at a higher horizon than the typical form, but is connected with that form by a perfectly-continuous series of intermediate stages.

*CLIOTHYRIS GLABRISTRIA* (Phil.). (Text-fig. 5.)

The general form is represented in Davidson, *op. supra cit.* pl. xviii, fig. 1 (*Athyris Royssii*).

This *Athyrid* is distinct, both in form and dimensions, from the typical *Cliothyris Royssii*, and it occurs, moreover, at a higher level, being especially characteristic of the *Zaphrentis*-Zone.

Fig. 5.—Cast of pedicle-valve of *Cliothyris glabristria*.



$a$  = Adductors.  $o$  = Ovarian markings,  
 $r$  = Diductors.  $d$  = Walls of pedicle-  
 cavity formed by the dental plates.

*Cliothyris glabristria* has, until now, been recorded from the Bristol area as '*Spirifera*' *glabra*, and it is extremely difficult, when the beak-region is obscured and the fringes are absent, to distinguish the two species one from the other by external characters alone.

The internal characters are, however, completely distinct:—

A *Martinia*, of which genus the true *Spirifer glaber* is the type, has no dental plates and inconspicuous muscular scars.

A *Cliothyris* has the internal characters common to all Athyrids,<sup>1</sup> namely:—

In the pedicle-valve: strong dental plates which form the tall, vertical walls of the pedicle-cavity. Elongated diductor-impressions, ruled lengthwise by strong parallel ridges (see fig. 5).

In the brachial valve: a strong mesial septum, with two pairs of narrow adductor-scars on either side.

*Reticularia* aff. *lineata* (see below, p. 299), which has, approximately, the same range as *Cliothyris glabristria*, has the same general form and the same internal characters (enumerated above); consequently, specimens of *Cl. glabristria* which retain the fringes have a remarkable resemblance to *Reticularia* aff. *lineata*. When the beak-region can be clearly made out, it is easy to distinguish the two species, by the fact that the apex of the beak in a *Reticularia* is typically non-perforate and the hinge-area is well developed. The two species are also satisfactorily separated by the under layer of fine close-set, radiating, scabriculate ribs which characterize the genus *Reticularia*; but even this character is somewhat simulated in the Athyrid by the occurrence of distant, radiating ridges beneath the outer layer of the test, which are represented on the cast by faint ridges.

#### CLIOTHYRIS GLABRISTRIA, mut.

At the top of  $Z_2$  we meet with elongate forms, transitional towards *Seminula ficoidea*, in which the characteristic fringes are merely suggested by faint striæ and the shell has acquired the tall beak and sloping shoulders of *S. ficoidea*.

In  $S_2$  of Burrington Combe, Weston,<sup>2</sup> and Lydstep an Athyrid occurs which exactly simulates *Cliothyris glabristria* in general form. The outer layer of the test is, however, produced into imbricating expansions, which do not form fringes as in a *Cliothyris*. Each of the expansions is a continuous sheet, with broad, low radial ribs; and specimens from which the expansions have been removed still exhibit a characteristic broad reticulation.

This form must be named *Athyris* cf. *glabristria*; it bears the same relationship to *Athyris planosulcata* that *Cliothyris glabristria* does to *Cliothyris Royssii*.

I have accepted with some hesitation Davidson's dictum that the figure to which reference is made above actually had a spinose investment, seeing that most of the specimens that I have examined from Midland and Northern localities appear to me to belong to *Athyris*, and not to *Cliothyris*.

#### Seminula.

The internal characters are the same, as regards septa and scars, for all Athyrids, and are illustrated by the diagram of *Cliothyris*

<sup>1</sup> These characters are less developed in *Cliothyris Royssii* than in *Cl. glabristria*, so that it is not difficult to separate the transverse variant of *Cl. Royssii* that rarely occurs in  $K_1$ , from a typical *Cliothyris glabristria* the external form of which it simulates.

<sup>2</sup> Mr. T. F. Sibly discovered this form at Weston, where it is abundant in certain beds. He has kindly allowed me to examine and describe his specimens.

*glabristria* (fig. 5) and by Davidson's figures of '*Athyris*' *ambigua* ('Monogr. Brit. Foss. Brachiop.' vol. ii, 1858-63, pl. xvii, figs. 13 & 14).

The absence of fringes (and therefore of external striations), together with the more Terebratuloid form, distinguishes *Seminula* from *Oliothyris*. The presence of internal spires separates *Seminula* from *Dielasma*.

#### SEMINULA FICOIDEA, Vaughan.

Described and figured in Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 122-24 & pl. ii, figs. 1-1 b.

#### SEMINULA AMBIGUA (Sow.), Davidson.

As represented in Davidson's 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xv, figs. 15-18 & pl. xvii, fig. 11 (*Athyris ambigua*).

I have seen very few specimens of this species in the Bristol area; the most typical of these were found in the Failand district at Horizon  $\delta$ . Mr. T. F. Sibly has, however, quite recently found the species abundant at the top of the *Syringothyris*-Zone, in the Burrington section (Northern Mendips), and near Weston; it is by his kindness that I am permitted to make this important statement, as to the zonal position of this well-known form.

A well-marked mutation occurs at the top of  $S_2$  and in D.

### Reticularia.

#### RETICULARIA aff. LINEATA (Martin).

The Bristol form, from the *Zaphrentis*-Zone, has usually a much deeper sinus than is represented in Davidson's 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xiii, fig. 9 & pl. xi, fig. 10 ('*Spirifera*' *lineata*), which are, however, the two figures that most closely represent our form.

This species has commonly been referred to '*Spirifer glaber*,' but the close-set radial ribs, under the outer layer of the test, and the internal characters of septa and muscular scars, leave no doubt as to its true generic position.<sup>1</sup> The typical lineation is usually conspicuous, but the surface is occasionally almost smooth. Impressions of the external surface often exhibit the concentric rows of twin-pores very beautifully.

The assimilation of this species to *Oliothyris glabristria* in general form has already been pointed out, but the well-developed area in *Reticularia* aff. *lineata* completely distinguishes the two forms.

#### 'SPIRIFER GLABER' (Martin), Davidson.

This species, as interpreted by Davidson, stands in need of careful revision, based on differences of internal structure. The typical *Martinia glabra* has not yet been met with in the Bristol area.

<sup>1</sup> Cf. James Hall, 'Thirteenth Ann. Rep. of the State Geologist N. Y. 1893-94': Introd. to the Study of Brachiop. pt. ii, pl. xxv, fig. 12.

### Spirifer.

SPIRIFER aff. CLATHRATUS, M'Coy, Vaughan. (Pl. XXVI, fig. 5.)

As interpreted in Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 125-27 & pl. ii, figs. 3-3 c. Also compare L. G. de Koninck, 'Sur le *Spirifer mosquensis* & sur ses Affinités avec quelques autres Espèces du même Genre' Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) pp. 371-402: *Sp. tornacensis*, de Kon. p. 386 & pl. xiii, figs. 1-9, and *Sp. cinctus*, A. de Keys. p. 383 & pl. xv, figs. 3-8.

The characters of this bisulcate *Spirifer* have been fully discussed in my paper above cited. I have merely to add that the two forms (which were erroneously described as mutations) can only be regarded as varieties, which are continuously connected by intermediate stages; their ranges are approximately the same, and therefore their distinction is a matter of no stratigraphical importance.

The large form, however, figured in pl. ii, fig. 3, Vaughan, *op. cit.*, resembles *Spirifer cinctus*, and is only common from the top of  $Z_1$  up to  $\gamma$ .

SPIRIFER aff. MOSQUENSIS, Fischer, de Kon.

Compare L. G. de Koninck, Bull. Mus. Roy. Hist. Nat. Belg. (1883) p. 379 & pl. xiv, figs. 1-11.

A few specimens of a form which is, apparently, closely allied to this species have been found in  $D_2$  (Avon section and Wick).

It is extremely interesting to note that the gens occupies the same position in the Bristol area as it does in Russia, namely, above the maximum of *Productus giganteus*.

SPIRIFER cf. GRANDICOSTATUS, M'Coy, Davidson (*pars*).

Non *Spirifera grandicostata*, M'Coy, 'Brit. Palæoz. Foss.' 1851, p. 417 & pl. iii D, fig. 29.

A *Spirifer*, similar to that figured by Davidson, in 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. vii, fig. 8, occurs rarely in  $D_2$ , in the Bristol and surrounding areas.

### Spiriferina.

SPIRIFERINA OCTOPLICATA (Sow.), Davidson. (Pl. XXVI, fig. 6.)

Compare Davidson, *op. cit.* pl. vii, fig. 40 & pl. liv, fig. 10.

The form figured by Davidson, *op. cit.* pl. vii, figs. 60 & 61, under the name of *Spiriferina partita*, Portlock, is extremely common at Horizon  $\beta$ . It is connected, by insensible gradations, with the more typical form which is characteristic of K.

### Syringothyris.

SYRINGOTHYRIS aff. LAMINOSA (M'Coy), (Davidson) *pars*.

Compare Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. vii, figs. 18 & 19 ('*Spirifera laminosa*'), and the area as shown in fig. 17.

The nature of the area, of the ribbing, and of the mesial fold and sinus are well expressed by Davidson's figures. The test is perforated by sparse tubuli (punctæ).

The very important internal characters are as follows:—Brachi

valve: short mesial septum. Pedicle-valve: strong dental plates; mesial septum. Within the delthyrium, there is a distinct rostral callus and a trace of syrinx. I have not as yet obtained unequivocal proof of the existence of a syrinx, but the presence of a rostral callus is indisputable.

The rostral callus and the mesial septum in the brachial valve, from their resemblance to similar structures in *Syringothyris cuspidata*, seem to be sufficient reason for assigning our specimens to the genus *Syringothyris* rather than to *Spiriferina*.

From *Spiriferina octoplicata* our species differs in the presence of:—(1) a rostral callus; (2) a mesial septum in the brachial valve; (3) much larger size and more numerous ribs; (4) and the ungrooved mesial fold.

From *Syringothyris cuspidata* our species differs in the strong and separate ribs, and also in the laminose ornament and the narrower, more concave area. From *Syringothyris distans* it differs in the absence of ribs on the fold, and in the sinus.

#### SYRINGOTHYRIS CUSPIDATA (Mart.).

The typical form, which is characteristic of the top of  $Z_2$  and C, is well depicted in Davidson's 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. viii, figs. 21-23 ('*Spirifera*' *cuspidata*).

*Syringothyris* aff. *cuspidata*, which is common from the top of  $K_1$  to Z, is a smaller form, with lower cardinal area and a narrow deep sinus which has, usually, tumid walls; the ribs on the pedicle-valve are broad and flat, and separated only by mere striae.

The gens of *Syringothyris cuspidata* seems to be essentially characteristic of the Tournaisian: it is abundantly represented from the top of  $K_1$  up to the top of C. It culminates in the very large typical form that appears to indicate the end of its long line of evolution. The occurrence of this large typical form seems consequently to mark a very definite and important datum-level, which has a true evolutionary basis.

#### Cyrtina.

##### CYRTINA CARBONARIA (M'Coy).

M'Coy, 'Brit. Palæoz. Foss.' 1851-55, p. 442 & pl. iii D, figs. 12-18 (*Pentamerus carbonarius*); Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. xv, figs. 5-14.

This species has not, as yet,<sup>1</sup> been definitely recognized in the Bristol area, but in surrounding areas it is an important zonal fossil and characterizes the Upper *Seminula*-Zone (Chépstow, Kidwelly, Weston, and Tenby).

#### Eumetria.

##### EUMETRIA spp.

James Hall, 'Thirteenth Ann. Rep. State Geologist N. Y. (1893-94): Introd. to Study of the Brachiop.' pt. ii, p. 795 & pl. xxxvii, figs. 1-12. Compare also *Retzia carbonaria*, Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii (1858-63) pl. li, fig. 3.

<sup>1</sup> See under Wickwar, p. 239, footnote.

I have not, as yet, sufficient material to be justified in assigning the Bristol forms to definite species.

The specimens agree with the definition of *Eumetria* in :—

- (1) The form and the absence of mesial fold and sinus.
- (2) Purely radial ribbing, without distinct axial symmetry.
- (3) Alate cardinal extremities in the brachial valve.
- (4) The elevated cardinal area, formed laterally of two concave, narrow strips, which are separated from the rest of the valve by strong ridges.
- (5) The triangular delthyrium and the foramen.

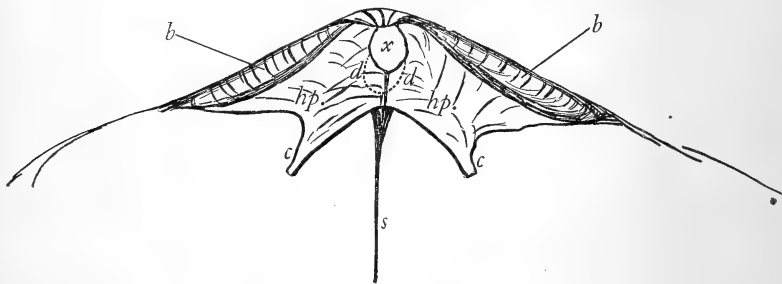
All the specimens are much smaller than the form figured by Davidson, and Davidson's figure is moreover unreliable, as it is merely a restoration of a very poor specimen<sup>1</sup> (which is preserved in the Museum of Practical Geology, Jermyn Street).

### **Camarotœchia.**

CAMAROTŒCHIA MITCHELDEANENSIS, sp. nov. (Pl. XXVI, figs. 7-7 b & text-fig. 6.)

External characters.—Shell small and slightly transverse; medial area of brachial valve flattened on the fold; median line of each valve strongly convex near the beak, but becoming less and less curved until, near the frontal margin, it is almost straight.

Fig. 6.—*Brachial valve of Camarotœchia mitcheldeanensis*:  
*plan of hinge-region.*



*s* = Mesial septum, splitting into two sheets near the beak, and supporting the hinge-plate along the suture-line *dd*.

*x* = Gap between the hinge-plates, which are in contact below (this gap is probably exaggerated in the specimen figured).

*hp* = The hinge-plates, from which the crural bases (*c*) project.

*b* = The sockets (crenulated).

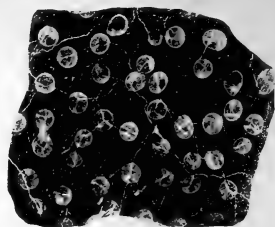
Fold and sinus well marked; their line of intersection deeply trapezoidal. Ribs angular, nearly straight, prominent from beak to margin, and separated by deep angular furrows; three (less commonly four) ribs on the fold; two (less commonly three) ribs in the sinus; five or six ribs on either flank of each valve.

<sup>1</sup> This specimen was obtained from Skrinkle Bay, and therefore from the same horizon as the Bristol forms.





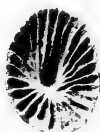
1



1a



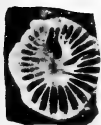
2



2a



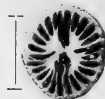
2b



2c



2d



2e



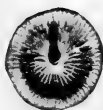
3



3a



3b



3c



3d

CARBONIFEROUS-LIMESTONE CORALS.



Beak small, narrow, pointed, curved, but not recurved. Area and delthyrium usually exposed to view.

Internal characters.—Pedicle-valve: Cardinal area represented by two narrow, concave strips, sharply marked off by ridges. Dental plates well developed, and forming the walls of the pedicle-cavity. Nospondylium. Brachial valve (see fig. 6, p. 302): Hinge-plate formed of two concave plates, which are separated by a gap at the beak, but are united below. Mesial septum well developed, and split near the beak into two separate sheets, which form the cruralium and support the hinge-plates. Dental sockets crenulated.

#### Dimensions.

Average transverse dimension = 11·5 millimetres; extreme = 14 mm.

Average axial dimension = 10 mm.; extreme = 12 mm.

Average normal dimension = 7 mm.

Trapezoidal intersection of fold and sinus: depth = 5·25 mm.; width, top and bottom = 2·75 mm. and 6 mm.

This shell has previously been recorded as a variety of *Rhynchonella pleurodon*, but it is so easily distinguished from typical examples of that species that mere convenience suggests its separation under a distinct specific name.<sup>1</sup> This course is rendered obligatory by the fact that *Camarotoechia mitchelleanensis* occurs in vast profusion in the Bristol and surrounding areas, and always characterizes the Lower Tournaisian rocks.

*C. mitchelleanensis* differs from the typical *Rhynchonella pleurodon* (such as is represented in Davidson, 'Monogr. Brit. Foss. Brachiop.' vol. ii, 1858–63, pl. xxiii, fig. 4) in the following characters:—

- (1) The shell is much smaller; (2) the fold is not relatively broad, and the intersection of the fold and sinus is not rectangular, but markedly trapezoidal; (3) the median line is strongly convex under the beak and becomes, continuously, less convex towards the front, but is never absolutely flat.

*Rhynchonella triplex*, McCoy, differs from our species, in the fact that the ribs in *Rh. triplex* become indistinct under the beak and the flank-ribs are limited to only three prominent ones.

*Camarotoechia pleurodon* (Phil.), as represented by the figures in Davidson, *op. cit.* pl. xxiii, includes forms from several horizons ( $Z_2$  at Clevedon,  $D_2$  at Wrington).

#### EXPLANATION OF PLATES XXII–XXIX.

##### PLATE XXII.

Figs. 1 & 1 a. *Syringopora*  $\theta$ .

Fig. 1. Exterior; natural size.

$Z_2$  subzone; Clevedon (Somerset).

1 a. Horizontal section;  $\times 1\cdot25$ .

$Z_2$  subzone; Clevedon (Somerset).

Figs. 2–2 c. *Zaphrentis* aff. *Phillipsi*, Edwards & Haime.

Fig. 2. Exterior; natural size.

*Zaphrentis*-Zone; Avon section, Clifton (Gloucestershire).  
(Collection of J. W. Tutchter, Esq.)

<sup>1</sup> The specimens figured in Pl. XXVI had been labelled 'var. or n. sp.'

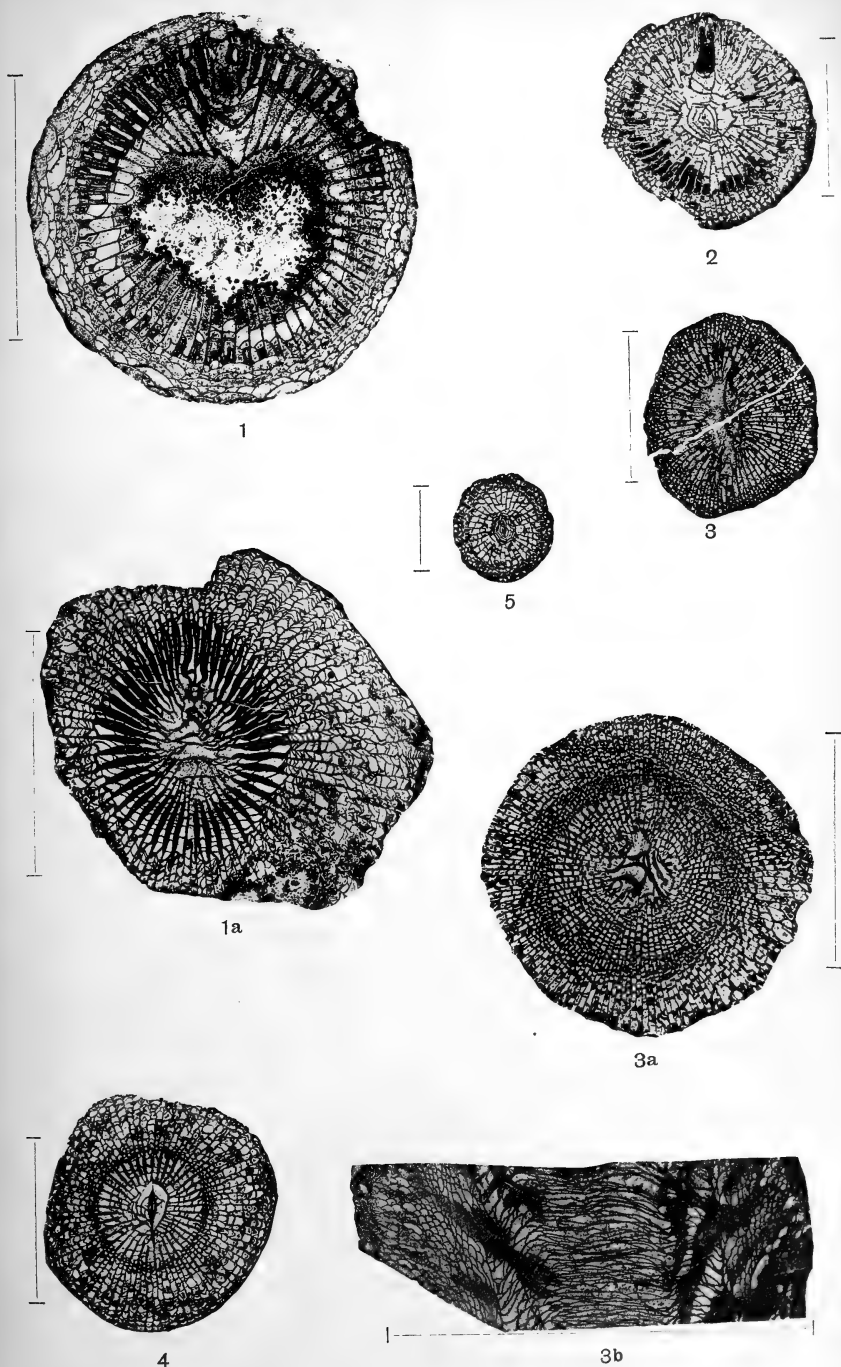
- Fig. 2 *a*. Calyx;  $\times 1.4$ .  
 Horizon  $\beta$ ; Avon section, Clifton (Gloucestershire).  
 2 *b*. Calyx of a very young example;  $\times 1.5$ .  
 Horizon  $\gamma$ ; Burrington section (Mendips), near Wrington (Somerset).  
 Figs. 2 *c*-2 *e*. Horizontal sections;  $\times 1.3$ .  
 Z<sub>2</sub> subzone. 2 *c*, 2 *d* from Portishead (Somerset). 2 *e* from Clevedon (Somerset).  
 Figs. 3-3 *d*. *Zaphrentis* aff. *cornucopiae* (Michelin).  
 Fig. 3. Exterior; natural size.  
 Z<sub>2</sub> subzone; Avon section, Clifton (Gloucestershire).  
 3 *a*. Calyx; natural size.  
 Z<sub>2</sub> subzone; Clevedon (Somerset).  
 Figs. 3 *b* & 3 *c*. Horizontal sections;  $\times 1.25$ .  
 Z<sub>2</sub> subzone. 3 *b* from Portishead (Somerset). 3 *c* from Clevedon (Somerset).  
 Fig. 3 *d*. Horizontal section of a very young example;  $\times 2.3$ .  
 Z<sub>2</sub> subzone; Clevedon (Somerset).

## PLATE XXIII.

- Figs. 1 & 1 *a*. *Caninia cylindrica* (Scouler).  
 Fig. 1. Mutation  $\gamma$ . Horizontal section of a small example;  $\times 1.5$ .  
 Horizon  $\gamma$ ; Burrington section (Mendips), near Wrington (Somerset).  
 1 *a*. Mutation S<sub>1</sub>. Horizontal section;  $\times 1.5$ .  
 S<sub>1</sub> subzone; Avon section, Leigh Woods, Bristol (Somerset).  
 Fig. 2. *Cyathophyllum*  $\theta$ . Horizontal section;  $\times 1.5$ .  
 Horizon  $\gamma$ ; Clevedon (Somerset).  
 Figs. 3-3 *b*. *Cyathophyllum*  $\phi$  = *Cyathophyllum Stutchburyi*, Ed. & H. (*pars*).  
 Fig. 3. Horizontal section of a young example;  $\times 1.4$ .  
 Horizon  $\delta$ ; Failand, near Bristol (Somerset).  
 3 *a*. Horizontal section of a typical example;  $\times 1.4$ .  
 Horizon  $\delta$ ; Failand, near Bristol (Somerset).  
 3 *b*. Part of the vertical section of a large example; natural size.  
 Horizon  $\delta$ ; Holwell (Mendips), near Frome (Somerset).  
 Fig. 4. *Koninckophyllum*  $\theta$ . Horizontal section;  $\times 1.5$ .  
 D<sub>1</sub> subzone; Sodbury (Gloucestershire).  
 5. A Clisiophyllid *Lithostrotion*. Horizontal section;  $\times 1.5$ .  
 D<sub>1</sub> subzone; Sodbury (Gloucestershire).

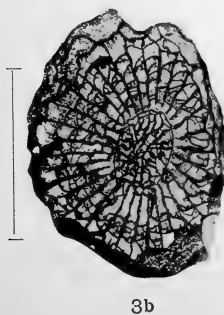
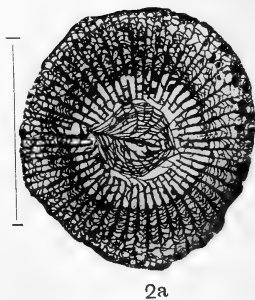
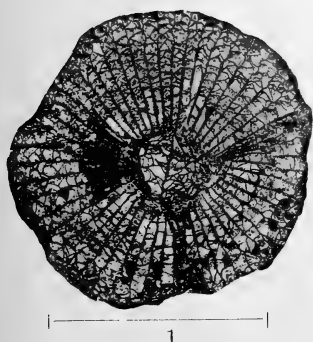
## PLATE XXIV.

- Fig. 1. *Dibunophyllum*  $\theta$ . Horizontal section;  $\times 1.5$ .  
 D<sub>1</sub> subzone; Flax Bourton, near Bristol (Somerset).  
 1 *a*. *Dibunophyllum*  $\phi$ . Exterior; very slightly reduced ( $\times .95$ ).  
 D<sub>1</sub> subzone; Flax Bourton, near Bristol (Somerset).  
 Figs. 2 & 2 *a*. *Dibunophyllum*  $\psi$ .  
 Fig. 2. Exterior;  $\times 1.2$ .  
 D<sub>2</sub> subzone; Rownham Hill, Leigh Woods, Bristol (Somerset).  
 2 *a*. Horizontal section;  $\times 1.45$ .  
 D<sub>2</sub> subzone; Rownham Hill, Leigh Woods, Bristol (Somerset).  
 Figs. 3-3 *b*. '*Clisiophyllum*' (*Carcinophyllum*)  $\theta$ .  
 Fig. 3. Calyx; natural size.  
 D<sub>1</sub> subzone; Sodbury (Gloucestershire).  
 3 *a*. Horizontal section;  $\times 1.43$ .  
 D<sub>1</sub> subzone; Flax Bourton, near Bristol (Somerset).  
 3 *b*. Horizontal section;  $\times 1.6$ . (To show variation in the structure of the central area.)  
 D<sub>1</sub> subzone; Sodbury (Gloucestershire).  
 Fig. 4. *Axophyllum*  $\theta$ . Horizontal section;  $\times 1.5$ .  
 D<sub>2</sub> subzone; Wrington (Somerset).



CARBONIFEROUS-LIMESTONE CORALS.

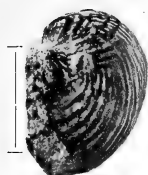




CARBONIFEROUS-LIMESTONE CORALS.







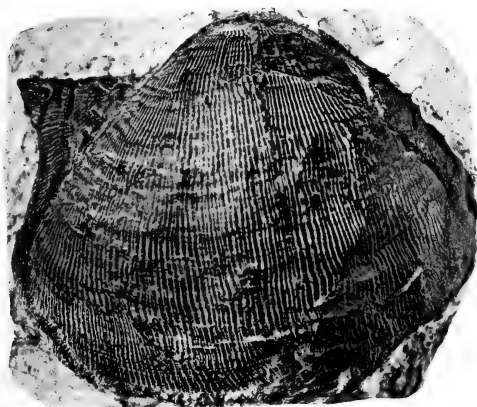
1a



1



2



3



2a



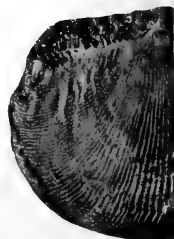
4a



4b



4

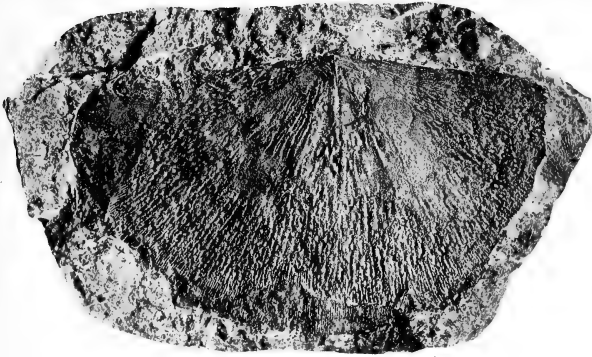


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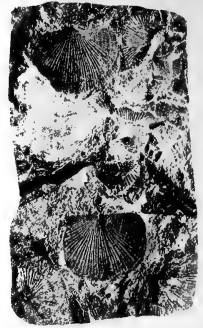
CARBONIFEROUS-LIMESTONE BRACHIOPODS.



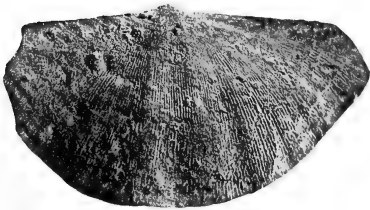




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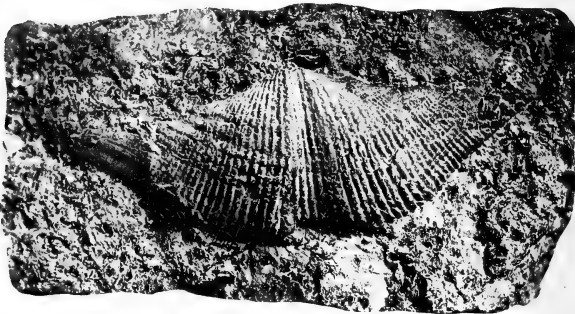
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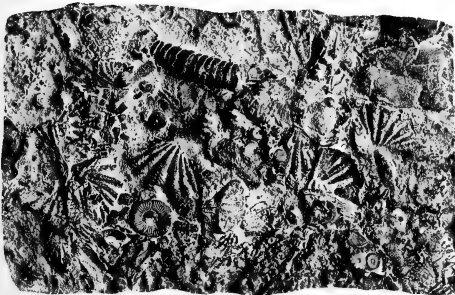
4



1



5



6



7a



7



7b

CARBONIFEROUS-LIMESTONE BRACHIOPODS.

## PLATE XXV,

- Figs. 1 & 1a. *Productus bassus*, sp. nov. Convex valve;  $\times 1.6$ .  
 $K_1$  subzone; Avon section, Leigh Woods (Somerset.)
- Figs. 2 & 2a. *Productus* cf. *Martini* (Sow.).<sup>1</sup> Convex valve; natural size.  
*Zaphrentis*-Zone; Moat-House Quarry, west of Failand, near Bristol (Somerset).
- Fig. 3. *Productus*  $\theta$ . Convex valve; natural size.  
 $S_1$  subzone; Great Quarry, Avon section, Clifton, Gloucestershire (Stoddart Coll.).
- Figs. 4-4b. *Productus* *Cora*, d'Orb., Davidson, mutation.  
 Convex valves of two examples; natural size.
- Fig. 4. The form characteristic of the  $S_2$  subzone.  $S_2$  subzone; Great Quarry, Avon section, Clifton (Gloucestershire).
- Figs. 4a & 4b. Variety with very fine ribbing.  $D_1$  subzone; Avon section, Leigh Woods (Somerset).
- Fig. 5. *Productus hemisphericus*, J. Sow., var. Convex valve; natural size.  
 $D_1$  subzone; Sodbury (Gloucestershire).  
 (Variety with coarse ribs and narrow beak.)

## PLATE XXVI.

- Figs. 1 & 2. The circulus of *Chonetes* cf. *hardrensis*, Phil.
- Fig. 1. *Chonetes* cf. *laquessiana*, de Kon. Convex valve; natural size.  
 $Z_1$  subzone; Burrington section (Mendips), near Wrington (Somerset).
2. *Chonetes* cf. *crassistria* (M'Coy). The two valves;  $\times 1.2$ .  
 Horizon  $\beta$ ; Failand section, near Bristol (Somerset).
- Fig. 3. *Chonetes* aff. *papilionacea*, Phil. Convex valve; natural size.  
 Base of *Syringothyris*-Zone; Cromhall, near Wickwar (Gloucestershire).  
 (One of the early papilionaceans.)
4. *Chonetes* aff. *comoides* (J. Sow.). Convex valve; natural size.  
 $D_1$  subzone; Sodbury (Gloucestershire.)
5. *Spirifer* aff. *clathratus*, M'Coy, Vaughan. Pedicle-valve; natural size.  
 $Z_1$  subzone; Failand section, near Bristol (Somerset).  
 (The transverse variety.)
6. *Spiriferina octoplicata* (Sow.), var. A slab showing several specimens; natural size.  
 Horizon  $\beta$ ; Walton Castle, near Clevedon (Somerset).  
 (J. W. Tutchter coll.)
- Figs. 7-7b. *Camarotoechia mitcheldeanensis*, sp. nov. Natural size.  
 (Cleistopora-zone); Mitcheldean (Gloucestershire).  
 (Museum of Practical Geology, Jermyn Street.)

## PLATE XXVII.

Vertical sections showing the thickness and lithology of the zones and sub-zones in the Carboniferous Limestone of the Bristol area, on the scale of 250 feet to the inch; horizontal section of the Avon Gorge, on the scale of 500 feet to the inch; and sketch-map of the quarries there.

## PLATE XXVIII.

Range-diagram of Carboniferous corals in the Bristol area, facing p. 244.

## PLATE XXIX.

Range-diagram of Carboniferous brachiopods in the Bristol area, facing p. 246.

<sup>1</sup> *Productus Flemingi* (Sow.) var. *burlingtonensis*, Hall ('Palæont. of N.Y.' vol. viii, pt. i, pl. xviii, figs. 6-8) is probably identical with *Pr.* cf. *Martini*, and occurs at the same horizon, namely, in the Burlington Limestone.

## DISCUSSION.

The PRESIDENT, who said that he had, some years ago, with Prof. Garwood, advocated the establishment of a Committee of the British Association for the study of Carboniferous zones, welcomed the Author's communication. Many years ago the late Prof. H. A. Nicholson had, in conversation, suggested that corals would prove useful as indices of Carboniferous zones, and it was satisfactory to hear that the Author had actually found them useful for this purpose.

Prof. GARWOOD wished to add his congratulations to those of the President, on the valuable work done by the Author for the advancement of our knowledge of the Carboniferous succession. He was struck by the difference in the fossils selected, from those characteristic of the Settle and Shap districts; but there seemed to be one exception to this, for the occurrence of *Spiriferina octoplicata* in the lower beds coincided with its occurrence in the Shap district.

Mr. H. B. WOODWARD remarked on the great advance made by the Author on the palæontological work done in the Bristol district by W. W. Stoddart and others. Mr. E. B. Wethered had urged the importance of the microscopic organisms in fixing horizons in the Carboniferous Limestone, but they could not be very serviceable to the field-geologist. With regard to the structure of the Clapton district, he (the speaker) was disposed to agree with Prof. Lloyd Morgan, that it was due chiefly to earth-movements.

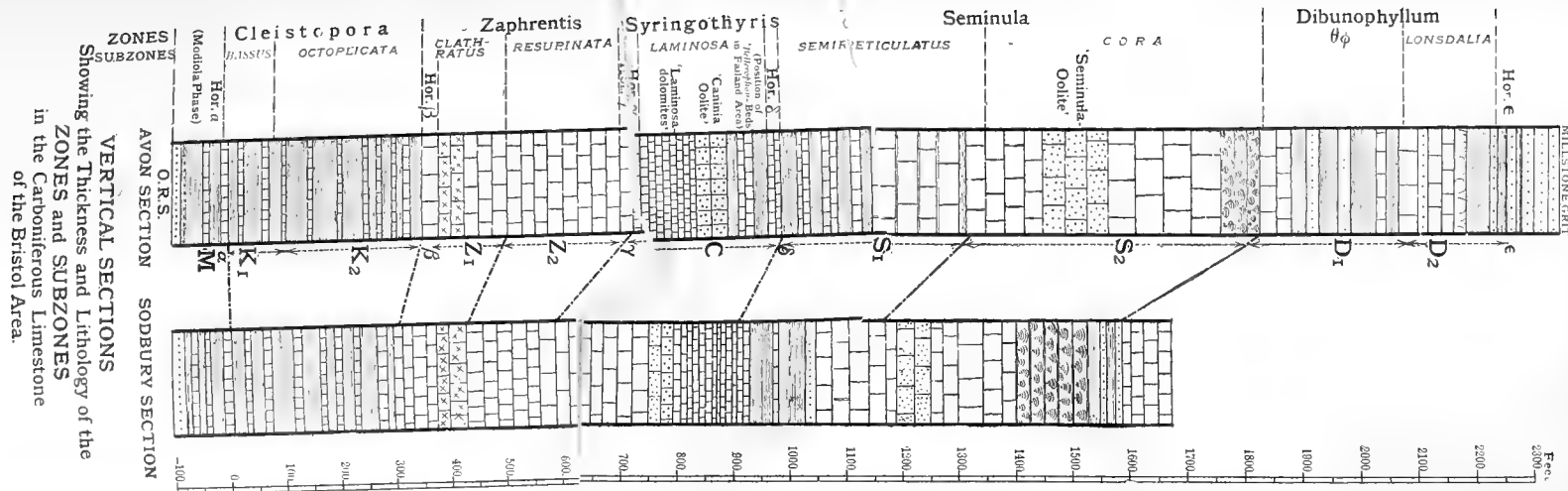
Dr. BATHER congratulated the Author on attacking this important problem in the only way that was likely to prove effective, namely, by the study of the stratigraphical relations of evolutionary series in limited groups of fossils. It was, however, necessary that the Author's opinions with regard to the relations of the numerous forms mentioned by him should be clearly understood. For this purpose his terminology should be precise. It did not seem to the speaker that the Author was using the term mutation in the sense ordinarily accepted by palæontologists, or the term circulus in the sense of its proposer, Prof. J. W. Gregory (Brit. Mus. Catal. Jurassic Bryozoa, pp. 14-22). Genus connotes a genetic affinity, denied by Gregory to those homœomorphic assemblages for which he adopted the provisional term circulus.

The Rev. J. F. BLAKE said that he had understood that the idea expressed by Prof. Gregory in the word circulus was the group of specimens which approximated more or less to the type of a species—like the persons who stood around a speaker, or other central object, in a public place in classic times—but round whom no very definite line of separation could be drawn. It was a modification of the old idea of a species. He understood the Author to use the word in this sense, and this use, combined with the reference to a single type for the central form, was very satisfactory to the speaker. He had understood also the word mutation in Waagen's sense, which was now well known. He regarded the paper as one of considerable promise, and looked forward to great results when

Observatory  
Hill  
Suspension  
Bridge Valley Rd.

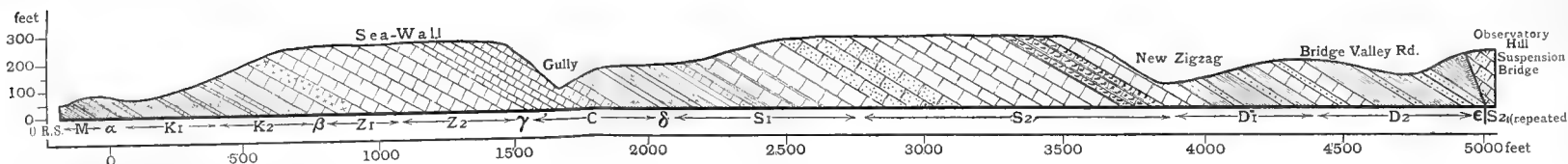
n. Geol. Soc. Vol. LXI, Pl. XXVII.





## THE ZONES IN THE AVON GORGE.

Horizontal Section. (Natural Scale.)



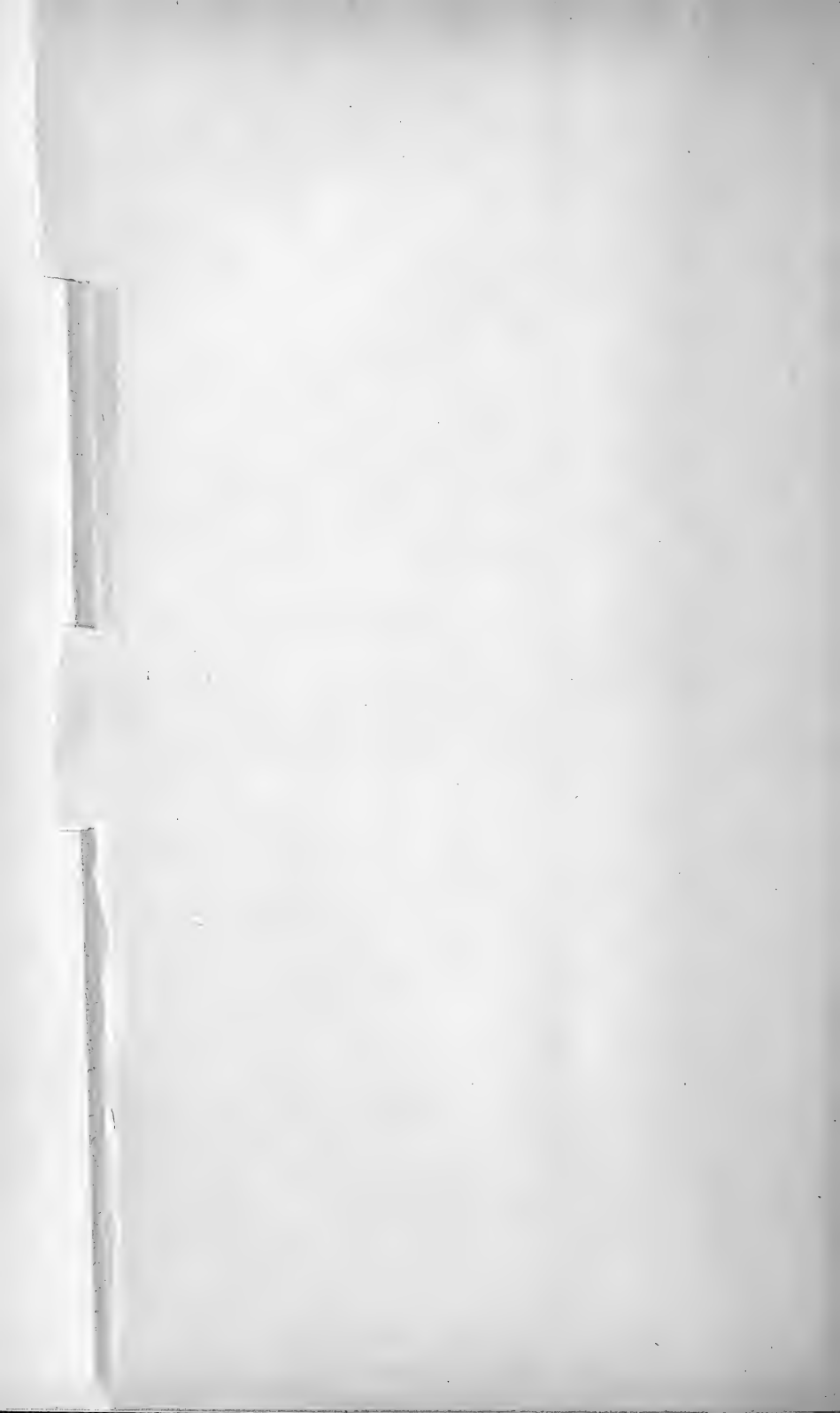
## SKETCH-MAP OF QUARRIES, &c.

TOURNAISIAN OR LOWER CARBONIFEROUS LIMESTONE.		ZONES AND SUBZONES.	
VISEAN OR UPPER CARBONIFEROUS LIMESTONE.	M	(MODIOLA-Phase).	
	K	CLEISTOPORA-Zone	K <sub>1</sub> = Subzone of <i>Productus bassus</i> . K <sub>2</sub> = Subzone of <i>Spiriferina octoplicata</i> .
	Z	ZAPHRENTIS-Zone	Z <sub>1</sub> = Subzone of <i>Spirifer aff. clathratus</i> . Z <sub>2</sub> = Subzone of <i>Schizophoria reispinata</i> .
	C	SYRINGOTHYRIS-Zone (including <i>laminosa</i> -subzone (C.) and Horizon $\delta$ ).	
	S	SEMINULA-Zone	S <sub>1</sub> = Subzone of <i>Productus semireticulatus</i> (mut.). S <sub>2</sub> = Subzone of <i>Productus aff. Cora</i> (mut. S <sub>2</sub> ).
	D	DIBUNOPHYLLUM-Zone	D <sub>1</sub> = Subzone of <i>Dibunophyllum</i> $\theta$ and <i>Dibunophyllum</i> $\phi$ . D <sub>2</sub> = Subzone of <i>Lonsdalia floriformis</i> .

HORIZONS (that is, faunal overlaps of Zones).

- a. Top of M, bottom of K.
- $\beta$ . Top of K, bottom of Z.
- $\gamma$ . Top of Z, bottom of C.
- $\epsilon$ . Top of C, bottom of S.
- e. Top of Carboniferous Limestone, bottom of 'Millstone-Grit' in the Bristol area.

[The CANINA-Zone includes Horizon  $\gamma$ , Zone C, and Subzone S<sub>1</sub>.]





questions were treated in this way, although he had lately heard the opinion expressed that the Carboniferous Limestone did not seem to lend itself to zoning.

The AUTHOR thanked the Fellows for their flattering reception of his paper, and expressed his especial gratitude to those who had taken part in the discussion, for their very kind remarks. In answer to Mr. H. B. Woodward, he regretted that he had not been able to find room, in a short abstract, either for a correlation of the zones, suggested in his paper, with the earlier lithological divisions, or for a reference to the work done by the late W. W. Stoddart in the Avon section. Both these subjects were, however, fully dealt with in the paper itself. In reply to Dr. Bather, he said that the term *circulus* was employed, throughout his paper, in a very definite sense. A *circulus* included all the forms which were very closely related to the type-species and were in perfect continuity with that species, either horizontally or vertically; it excluded all apparently-similar forms which were separated by a long vertical interval from the occurrence of the type, and were not connected with the type by a chain of similar forms. The Author had adopted the term *circulus* from Prof. Gregory's work on the Jurassic Bryozoa under the same impression as the Rev. J. F. Blake, that it very conveniently covered the whole group, which was composed of the type-species and its close relatives. Should, however, Dr. Bather's interpretation be the correct one, namely, that the term *circulus* was originally intended to cover a heterogeneous assemblage of similar forms, for which even genetic relationship could not be claimed, a new term would have to be introduced to convey the meaning in which the term *circulus* was employed in the present paper.

With regard to the use of the term *mutation*, it was undoubtedly employed in this paper to denote lateral, as well as vertical, variation from a type-species. The Author considered that both lateral and vertical variation were equally cases of evolutionary change, seeing that at least one important factor in lateral variation was direct evolution during migration. It would be impossible to discriminate between the action of this factor and of the other recognized cause, namely, direct evolution from distinct members of a *circulus*, which took place contemporaneously at distant points.

12. *On the DIVISIONS and CORRELATION of the UPPER PORTION of the COAL-MEASURES, with special reference to their DEVELOPMENT in the MIDLAND COUNTIES of ENGLAND.* By ROBERT KIDSTON, F.R.S. L. & E., F.G.S. (Read April 5th, 1905.)

WHILE working out the flora of the British coalfields, I have found no group of rocks more interesting than the group of sandstones and marls, frequently of a red, purple, or mottled colour, and their associated limestones, which lie above the Middle Coal-Measures of the Potteries Coalfield.

When preparing my paper on 'The Fossil Flora of the Coalfield of the Potteries,'<sup>1</sup> the classification which I adopted was that used by Mr. John Ward,<sup>2</sup> but at that time little was known about the thickness and stratigraphical relationship of the beds forming this group. The classification adopted by Mr. Ward is as follows:—

PERMIAN ROCKS .....	{ Red Marls.
	{ Red Sandstone.
	{ 1. Upper Coal-Measures.
	{ 2. Middle Coal-Measures.
	{ 3. Lower Coal-Measures.
CARBONIFEROUS ROCKS .....	{ 4. Millstone-Grit.
	{ 5. Yoredale Rock.
	{ 6. Carboniferous Limestone.

In the present paper my remarks will be restricted to the rocks here called Permian and Upper Coal-Measures. Any reference that may be made to the underlying group will be merely incidental.

At the time when my paper on the fossil flora of the Potteries Coalfield was written, I had seen no plants from the so-called 'Permian' of that area, and, in regard to these rocks, Mr. John Ward says, in the work already mentioned:—

'I may here remark that a considerable development of red, purple, and variegated marls which have been coloured by the Geological Survey as Permian are, I am inclined to think, in reality Upper Coal-Measures.' (*Op. cit.* p. 14 [sep. cop.].)

That these rocks were Carboniferous and not Permian, I felt quite certain: for, apparently, the same so-called 'Permian' rocks were passed through while sinking the shaft of the Hamstead Colliery at Great Barr, near Birmingham; they contained a typical Upper Coal-Measure flora; and with this series I classed them at the time.<sup>3</sup>

<sup>1</sup> Trans. Roy. Soc. Edin. vol. xxxvi (1890-92) pp. 63-98.

<sup>2</sup> 'The Geological Features of the North Staffordshire Coalfields, their Organic Remains, their Range & Distribution; with a Catalogue of the Fossils of the Carboniferous System of North Staffordshire' Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x (1890) p. 4 [sep. cop.].

<sup>3</sup> 'On the Fossil Flora of the Staffordshire Coalfields. Part I. On the Fossil Plants collected during the Sinking of the Shaft of the Hamstead Colliery, Great Barr, near Birmingham' Trans. Roy. Soc. Edin. vol. xxxv (1888-90) pp. 317-35.

Messrs. F. G. Meachem & H. Insley had previously referred these rocks to the Upper Coal-Measures.<sup>1</sup> I shall have occasion to refer to the Upper Coal-Measures of Great Barr later on in this paper.

The dividing-line between the Upper and Middle Coal-Measures, adopted in the Potteries Coalfield, was a *Spirorbis*-Limestone, 12 yards above the Bassey-Mine Ironstone.

From the entire series of rocks above this line, the only plants met with up to the time mentioned above were :—

*Pecopteris arborescens* (Schl.).

*Pecopteris cyathea* (Schl.).

*Mariopteris muricata* (Schl.).

*Alethopteris aquilina* (Schl.).

*Alethopteris lonchitica* (Schl.).

*Odontopteris* sp.

*Neuropteris ovata*, Hoffm.

*Calamites Suckowi*, Brongn.

*Calamocladus equisetiformis* (Schl.).

*Lepidostrobus variabilis*, L. & H.

*Sigillaria Brardi*, Brongn.

*Stigmaria ficoides* (Sternb.).

*Rhabdocarpus sulcatus* (Presl).

The whole of these species, except *Rhabdocarpus sulcatus*, occur in the Upper Coal-Measures, though some are very rare therein, and several of the plants are much commoner in the Middle and Lower Coal-Measures.

When dealing with the general classification of the British Carboniferous rocks as determined by their fossil plants,<sup>2</sup> I mentioned that Dr. Wheelton Hind<sup>3</sup> had discovered, in rocks a few yards above the *Spirorbis*-Limestone, specimens of *Neuropteris gigantea*, Sternb., *N. heterophylla*, Brongn., and *Sphenophyllum emarginatum*, Brongn., and, at a later date, *Sigillaria ovata*, Sauveur.<sup>4</sup>

Of these, the only one known to occur in the Upper Coal-Measures was *Sphenophyllum emarginatum*, and of the other three, *Sigillaria ovata* was a typical Middle Coal-Measure species, while the two *Neuropteris* were common to both the Middle and Lower Coal-Measures<sup>5</sup>; it was therefore evident that the lower part, at least, of the group which had been referred to the Upper Coal-Measures belonged to my Transition Series, a division that I had proposed for certain beds lying between the Middle and the Upper Coal-Measures, and the flora of which was characterized by an admixture of Upper and Middle Coal-Measure species. This series forms a most natural and important group. When preparing the 'Additional Records & Notes' (*op. cit.* p. 129), in referring to this Transition Series, I said :—

'This series appears to be very feebly developed in the Potteries Coalfield, though it may form a more important group than is at present suspected.'

This suggested possibility has proved to be the case, and the rocks

<sup>1</sup> Rep. Brit. Assoc. 1886 (Birmingham) p. 626.

<sup>2</sup> 'On the Various Divisions of British Carboniferous Rocks, as determined by their Fossil Flora' Proc. Roy. Phys. Soc. Edin. vol. xii (1893-94) pp. 183-257.

<sup>3</sup> *Op. cit.* p. 229.

<sup>4</sup> 'Additional Records & Notes on the Fossil Flora of the Potteries Coalfield, North Staffordshire' Trans. North Staffs. Field-Club, vol. xxxi (1897) p. 127.

<sup>5</sup> A single example of *Neuropteris heterophylla* has quite recently been found in the 'Keele Group' = Upper Coal-Measures.

to which I applied the name of Transition Series have proved to be a most important group, not only in the Potteries Coalfield, but in other areas of the Midland Counties of England.

In 1895, the Geological Survey commenced a re-survey of the Potteries Coalfield, and in 1902 the Memoir of 'The Geology of the Country around Stoke-upon-Trent' was published.<sup>1</sup> Here, for the first time,<sup>2</sup> Mr. Walcot Gibson gives a full account of the rocks lying above the Middle Coal-Measures of the Potteries Coalfield, and accepts as their base the Bassey-Mine Ironstone. This brings down the dividing-line between the Middle Coal-Measures and the overlying strata 36 feet; but Mr. Gibson considers the Bassey-Mine Ironstone a more convenient line of division than the *Spirorbis*-Limestone previously accepted, and this 'line' has now been adopted.

The following are the subdivisions of the rocks overlying the Middle Coal-Measures of North Staffordshire, as tabulated by Mr. Walcot Gibson (Mem. Geol. Surv. *jam cit.* p. 37):—

<i>Name of Subdivision.</i>	<i>Characters.</i>	<i>Thickness.</i>
KEELE GROUP.	Red and purple sandstones and marls. Occasional seams of coal. Thin black and grey limestones, and subordinate bands of grey sandstone and shale. Base, entomostracan shale.	Over 700 feet at Keele Park. Summit nowhere visible, unless at Moddershall.
NEWCASTLE-UNDER-LYME GROUP.	Grey sandstones and shales, with four thin seams of coal. Base, entomostracan limestone.	300 feet.
ETRURIA-MARL GROUP.	Chiefly mottled red and purple marls and clays. Thin beds of green grit very characteristic. Limestone-bands near the summit and base. Lenticular mass of grey sandstone overlying a laminated ironstone and thin coal 150 feet above the base (Chester-ton only). Base, often a greenish fine-grained sandstone.	800 to 1100 feet.
BLACKBAND GROUP.	Chiefly sandstones, marls, and clays. Some lenticular bands of grey grit and slightly-mottled marls. Numerous thin seams of coal and Blackband ironstones. Thin bands of limestone throughout the series, one of which is constant at 36 to 40 feet above the Bassey-Mine Coal.	300 to 450 feet.

Since my last notes on the fossil flora of the Potteries Coalfield were published in 1897, the fossil plants from this group have been

<sup>1</sup> Mem. Geol. Surv. 1902, 'The Geology of the Country around Stoke-upon-Trent. (Explanation to Sheet 123.)' By Walcot Gibson & C. B. Wedd; with Notes by George Barrow.

<sup>2</sup> A preliminary account of these rocks was given by Mr. Gibson, in his paper, 'On the Character of the Upper Coal-Measures of North Staffordshire, Denbighshire, South Staffordshire, & Nottinghamshire; & their Relation to the Productive Series' Quart. Journ. Geol. Soc. vol. lviii (1901) p. 251.

carefully collected; but such remains are very scarce in these rocks, and are especially rare in the *Etruria*-Marl Group, from which I have only been able to identify a single species.<sup>1</sup>

So far as known to me, the following table embodies a list of all the fossil plants observed in the upper series of the Potteries Coal-field:—

TABLE OF THE FOSSIL PLANTS OF THE KEELE, NEWCASTLE, ETRURIA, AND BLACKBAND GROUPS.

SPECIES.	I. <i>Keele</i> Group.	II. <i>Newcastle- under-Lyme</i> Group.	III. <i>Etruria- Marl</i> Group.	IV. <i>Black- band</i> Group.
<i>Sphenopteris obtusiloba</i> , Brongn. ....	...	*		
<i>Pecopteris arborescens</i> (Schl.) ....	...	*		
<i>Pecopteris cyathea</i> (Schl.) ....	*	*		
<i>Pecopteris Miltoni</i> (Artis) ....	*	*	...	*
<i>Mariopteris nauricata</i> (Schl.) ....	...	...	...	*
<i>Alethopteris aquilina</i> (Schl.) ....	...	*		
<i>Alethopteris lonchitica</i> (Schl.) ....	...	*		
<i>Alethopteris valida</i> , Boulay ....	...	...	...	*
<i>Odontopteris</i> sp. ....	...	*		
<i>Neuropteris acuminata</i> (Schl.) ? ....	...	...	...	*
<i>Neuropteris heterophylla</i> , Brongn. ....	...	...	...	*
<i>Neuropteris macrophylla</i> , Brongn. (?) ....	...	...	...	*
<i>Neuropteris tenuifolia</i> (Schl.) ? ....	...	...	...	*
<i>Neuropteris ovata</i> , Hoffm. ....	...	*		
<i>Neuropteris rarinervis</i> , Bunbury ....	...	*	...	*
<i>Neuropteris gigantea</i> , Sternb. ....	...	*	...	*
<i>Neuropteris Scheuchzeri</i> , Hoffm. ....	*	*	*	
<i>Linopteris Münsteri</i> (Eichw.) ....	...	...	...	*
<i>Linopteris obliqua</i> (Bunbury) ..	...	...	...	*
<i>Calamites Cisti</i> , Brongn. ....	?			
<i>Calamites Schützei</i> , Stur ....	*			
<i>Calamites undulatus</i> , Sternb. ....	*			
<i>Calamites Suckowi</i> , Brongn. ....	*	*	...	*
<i>Calamites varians</i> , Sternb. ....	...	...	...	*
<i>Calamites waldenburgensis</i> , Stur. ....	...	...	...	*
<i>Calamocladus equisetiformis</i> (Schl.) ....	...	*	...	*
<i>Annularia galioides</i> (L. & H.) ....	...	...	...	*
<i>Annularia radiata</i> , Brongn. ....	...	...	...	*
<i>Macrostachya infundibuliformis</i> (Brongn.) ..	...	...	...	*
<i>Sphenophyllum cuneifolium</i> (Sternb.) ..	...	...	...	*
<i>Sphenophyllum emarginatum</i> , Brongn. ....	...	*	...	*
<i>Lepidodendron lycopodioides</i> , Zeiller (Stbg.) ..	...	*		
<i>Lepidodendron ophiurus</i> , Brongn. ....	...	*		
<i>Lepidodendron Wortheni</i> , Lesq. ....	...	...	...	*
<i>Lepidophyllum lanceolatum</i> , L. & H. ....	...	*		
<i>Lepidostrobis variabilis</i> , L. & H. ....	...	*		

<sup>1</sup> I am indebted to Mr. John Ward, F.G.S., Dr. W. Hind, F.G.S., and to Mr. John T. Stobbs, F.G.S., for kindly submitting to me their plant-collections from these groups; to them my knowledge of the flora is almost entirely due. I have also had sent to me some specimens collected by the late Dr. Garner, which are contained in the collection of the Stoke-upon-Trent Museum.

TABLE OF THE FOSSIL PLANTS OF THE KEELE, ETC. GROUPS (*continued*).

SPECIES.	I. <i>Keele</i> <i>Group.</i>	II. <i>Newcastle-</i> <i>under-Lyme</i> <i>Group.</i>	III. <i>Etruria-</i> <i>Marl</i> <i>Group.</i>	IV. <i>Black-</i> <i>band</i> <i>Group.</i>
<i>Lepidostrobus anthemis</i> (König) .....	...	...	...	*
<i>Sigillaria tessellata</i> , Brongn. (?).....	*			
<i>Sigillaria Brardi</i> , Brongn. ....		*		
<i>Sigillaria discophora</i> (König) .....	...	...	...	*
<i>Sigillaria ichthyolepis</i> , Sternb. (Weiss) .....	...	...	...	*
<i>Sigillaria ovata</i> , Sauveur .....	...	...	...	*
<i>Stigmaria ficoides</i> (Sternb.).....	...	*	...	*
<i>Cordaïtes borassifolius</i> (Sternb.) .....	...	...	...	*
<i>Artisia transversa</i> (Artis).....	...	*	...	*
<i>Trigonocarpus Parkinsoni</i> , Brongn. . . . .	...	...	...	*
<i>Rhabdocarpus sulcatus</i> (Presl) <sup>1</sup> .....	...	*		

Reference has already been made to the plants found in the so-called 'Permian' rocks, passed through in sinking the shaft of the Hamstead Colliery, Great Barr, near Birmingham. The beds which yielded the plants extended from a depth of 729 to 1233 feet below the surface, and are undoubtedly referable to the Upper Coal-Measures; they are, I think, equally certainly the Keele Group of the Potteries Coalfield. Beds above these, extending downwards from 627 feet below the surface, belong, I believe, to the same group, but they did not yield any fossil plants.

<sup>1</sup> The following is a list of the fossil plants observed in the Newstead Boring, Trentham (North Staffordshire), all of which are included in the above list:—

SPECIES.	I. <i>Keele</i> <i>Group.</i>	II. <i>Newcastle-</i> <i>under-Lyme</i> <i>Group.</i>	III. <i>Etruria-</i> <i>Marl</i> <i>Group.</i>	IV. <i>Black-</i> <i>band</i> <i>Group.</i>
<i>Pecopteris cyathea</i> (Schl.) .....	*			
<i>Pecopteris Miltoni</i> (Artis) .....	*	*		
<i>Neuropteris</i> sp. ....	*			
<i>Neuropteris acuminata</i> (Schl.) ? .....	...	...	...	*
<i>Neuropteris heterophylla</i> , Brongn. ....	...	...	...	*
<i>Neuropteris tenuifolia</i> (Schl.) ? .....	...	...	...	*
<i>Neuropteris rarinervis</i> , Bunbury .....	...	*		
<i>Neuropteris Scheuchzeri</i> , Hoffm. ....	*			
<i>Linopteris Münsteri</i> , Eichw. ....	...	...	...	*
<i>Linopteris obliqua</i> , Bunbury .....	...	...	...	*
<i>Calamites undulatus</i> , Sternb. ....	*			
<i>Calamocladus equisetiformis</i> (Schl.) .....	...	*		
<i>Annularia radiata</i> , Brongn. ....	...		...	*
<i>Sphenophyllum emarginatum</i> , Brongn. ....	...	*		
<i>Lepidodendron lycopodioides</i> , Zeiller (Stbg.) .....	...	*		
<i>Lepidostrobus</i> sp. ....	...	*		
<i>Cordaïtes borassifolius</i> (Sternb.) .....	...	...	...	*

A bed reached at a depth of 1320 feet from the surface, and 72 feet thick, may belong to the Keele Group; but I am rather inclined to regard it as referable to the Newcastle-under-Lyme Group. The plants from this bed, though all but one occur in the Upper Coal-Measures, are commoner in the Middle Coal-Measures, and there is no characteristic Upper Coal-Measure plant found among them.

The supposed unconformity, which brings the Newcastle-under-Lyme Group (?) against the Middle Coal-Measures in this section, is much more probably the result of a fault: since, with the exception of this possible unconformity, the Keele Group has been found always conformable to the underlying Coal-Measures.

LIST OF FOSSIL PLANTS OBTAINED WHILE SINKING THE SHAFT OF THE HAMSTEAD COLLIERY, GREAT BARR, NEAR BIRMINGHAM. [For condensed section, see Trans. Roy. Soc. Edin. vol. xxxv (1888) p. 318. The Upper Coal-Measures probably end at a depth of about 1233 feet.]

SPECIES.	I.	II.
	<i>Keele Group</i> = <i>Upper Coal-Measures</i> . Depth: 729 to 1233 feet.	<i>Newcastle-under-Lyme Group (?)</i> . Depth: 1236 to 1320 feet.
<i>Pecopteris arborescens</i> (Schl.) .....	*	
<i>Pecopteris Miltoni</i> (Artis) .....	*	
<i>Pecopteris unita</i> , Brongn. ....	*	
<i>Alethopteris aquilina</i> (Schl.) .....	*	
<i>Odontopteris Lindleyana</i> , Sternb. ....	*	
<i>Neuropteris flexuosa</i> , Sternb. ....	*	
<i>Neuropteris ovata</i> , Hoffm. ....	*	
<i>Neuropteris rarinervis</i> , Bunbury .....	*	
<i>Neuropteris Scheuchzeri</i> , Hoffm. ....	*	
<i>Calamites</i> sp. ....	*	
<i>Annularia stellata</i> (Schl.) .....	*	
<i>Sphenophyllum emarginatum</i> , Brongn. ....	*	
<i>Lepidophyllum lanceolatum</i> , L. & H. ....	*	
<i>Lepidostrobus</i> sp. ....	*	
<i>Stigmaria ficoides</i> (Sternb.) .....	*	
<i>Cyperites bicarinata</i> , L. & H. ....	*	
<i>Cordaites angulosostriatus</i> , Grand'Eury ...	*	
<i>Walchia imbricata</i> , Schimper .....	*	
<i>Alethopteris decurrens</i> (Artis) .....	...	*
<i>Calamites Suckowi</i> , Brongn. ....	...	*
<i>Calamites undulatus</i> , Sternb. ....	...	*
<i>Calamites varians</i> , Sternb. ....	...	*
<i>Lepidodendron Wortheni</i> , Lesq. ....	...	*
<i>Lepidostrobus variabilis</i> , L. & H. ....	...	*
<i>Sigillaria</i> sp. ....	...	*
<i>Artisia approximata</i> (Brongn.) .....	...	*
<i>Pinnularia capillacea</i> , L. & H. ....	...	*

In 1876, Mr. D. C. Davies pointed out that certain upper beds in Denbighshire, which had been mapped as Permian, should probably be classed as Carboniferous.<sup>1</sup> This area was subsequently visited by Mr. Walcot Gibson, who identified in these supposed 'Permian' rocks of Denbighshire and Upper Coal-Measures, the three Carboniferous subdivisions which occur in North Staffordshire, and named by him the Keele Group, the Newcastle-under-Lyme Group, and the Etruria-Marl Group. As equivalent terms for the Denbighshire representatives he has proposed the following:—

NORTH STAFFORDSHIRE.	DENBIGHSHIRE.
Keele Group	= Wrexham Red Sandstones and Marls.
Newcastle-under-Lyme Group	= Coedyrallt Group.
Etruria-Marl Group	= Ruabon Marls. <sup>2</sup>

While collecting fossil plants in Denbighshire in 1903, Mr. J. Pringle gave particular attention to the examination of these rocks, but found them very barren of plant-remains. The only species collected were:—

SPECIES.	Keele Group = Wrexham Group.	Newcastle Group = Coedyrallt Group.	Etruria-Marl Group = Ruabon Marls.
<i>Pecopteris unita</i> , Brongn. ....	*		
<i>Pecopteris Miltoni</i> (Artis) .....	...	*	
<i>Pecopteris (Cyathites)</i> sp. ....	...	*	
<i>Alethopteris aquilina</i> (Schl.) .....	...	*	
<i>Neuropteris rarinervis</i> , Bunbury .....	...	*	
<i>Calamocladus equisetiformis</i> (Schl.) .....	...	*	
<i>Lepidodendron lycopodioides</i> , Zeiller (Stbg.) ...	...	*	
<i>Cordaites principalis</i> (Germer) .....	...	*	

From the Ruabon Marls not a single specimen was found. This agrees with the almost-total barrenness of the Etruria Marls of North Staffordshire, from which a single species is recorded. The few species found in these groups in Denbighshire agree with those observed in the corresponding groups in North Staffordshire.

Passing northwards to Cumberland, a series of red and purple shales, occurring in Jockie's Syke, 1 mile east by north of Riddings Junction, were found by Mr. A. Macconochie, in 1879, to contain Upper Coal-Measure plants. This locality was again visited by

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 10.

<sup>2</sup> *Ibid.* vol. lvii (1901) p. 261.



Mr. Macconochie and myself in 1902, when the following species were collected :—

*Pecopteris arborescens* (Schl.).

*Pecopteris* (*Cyatheites*) sp.

*Alethopteris aquilina* (Schl.).

*Alethopteris Grandini* (Brongn.).

*Alethopteris Serli* (Brongn.).

*Neuropteris flexuosa*, Sternb.

*Neuropteris ovata*, Hoffm.

*Neuropteris Scheuchzeri*, Hoffm.

*Calamites undulatus*, Sternb.

*Calamites* sp.

*Calamocladus equisetiformis* (Schl.).

*Annularia radiata*, Brongn.

*Annularia stellata* (Schl.).

*Lepidodendron fusiforme* (Corda).

*Lepidophyllum* sp.

*Stigmaria ficoides* (Sternb.).

These beds I unhesitatingly refer to the Upper Coal-Measures, but at the same time regard them as identical with the Keele Group of North Staffordshire.<sup>1</sup>

Before proceeding further, it will be well to collect all the plant-records from the Keele Group, with which I correlate the plant-bearing beds of Jockie's Syke (Cumberland), and the upper part of the 'Red Rocks' passed through in the Hamstead Boring at Great Barr, near Birmingham; those from the Newcastle-under-Lyme Group, the Etruria-Marl Group and the Blackband Group of North Staffordshire, as these have been defined by Mr. Walcot Gibson.<sup>2</sup>

These beds are known, in part or in whole, to occur in South Staffordshire, Shropshire, Denbighshire, Nottinghamshire, Lancashire, and Cumberland, and also in the South-Wales Coalfield, Somerset, and the Forest of Dean; and they may occur in Yorkshire as well. But in some of these counties, although there is no doubt as to the occurrence of these groups in part or in whole, they still require further examination before their full extent can be determined.

In connection with this subject, reference must be made to the fossil plants of the 'Ardwick Series' of Manchester (which have been described by Mr. E. A. N. Arber), and the evidence which they afford as to the age of the beds discussed, with the result that he ascribes the Ardwick Series to my 'Transition Series.'<sup>3</sup> This is most probably their position, but the exact horizon of the specimens examined by Mr. Arber was not ascertainable. The plant-evidence, however, shows clearly that part of the Ardwick Series, if not the whole, belongs to that group of rocks which have been termed the Transition Series, and are so well developed in the Potteries Coalfield (North Staffordshire).

<sup>1</sup> B. N. Peach & J. Horne, 'The Canonbie Coalfield: its Geological Structure & Relations to the Carboniferous Rocks of the North of England & Central Scotland' Trans. Roy. Soc. Edin. vol. xl (1903) p. 858; and R. Kidston, 'The Fossil Plants of the Carboniferous Rocks of Canonbie (Dumfriesshire), & of Parts of Cumberland & Northumberland' *ibid.* p. 802.

<sup>2</sup> Mem. Geol. Surv. 1902, 'The Geology of the Country around Stoke-upon-Trent' pp. 35-47.

<sup>3</sup> Mem. & Proc. Manch. Lit. & Phil. Soc. vol. xlviii (1903) no. 2, pp. 22-23.

TABLE OF THE DISTRIBUTION OF THE PLANTS IN THE KEELE GROUP, THE NEWCASTLE-UNDER-LYME GROUP, THE ETRURIA-MARL GROUP, AND THE BLACKBAND GROUP.

SPECIES.	I. <i>Keele</i> <i>Group.</i>	II. <i>Newcastle</i> <i>Group.</i>	III. <i>Etruria</i> <i>Group.</i>	IV. <i>Black-</i> <i>band</i> <i>Group.</i>
<i>Sphenopteris obtusiloba</i> , Brongn. ....	...	...	...	*
<i>Pecopteris arborescens</i> (Schl.) ....	*	*		
<i>Pecopteris cyathea</i> , Brongn. ....	*	*		
<i>Pecopteris unita</i> , Brongn. ....	*			
<i>Pecopteris Miltoni</i> (Artis) ....	*	*	...	*
<i>Mariopteris muricata</i> (Schl.) ....	...	...	...	*
<i>Alethopteris lonchitica</i> (Schl.) ....	...	*		
<i>Alethopteris decurrens</i> (Artis) ....	...	(?)		
<i>Alethopteris aquilina</i> (Schl.) ....	*	*		
<i>Alethopteris Grandini</i> (Brongn.) ....	*			
<i>Alethopteris Serli</i> (Brongn.) ....	*			
<i>Alethopteris valida</i> , Boulay ....	...	...	...	*
<i>Odontopteris Lindleyana</i> , Sternb. ....	*			
<i>Odontopteris</i> sp. ....		(?)		
<i>Neuropteris heterophylla</i> , Brongn. ....	*	...	...	*
<i>Neuropteris acuminata</i> (Schl.) ? ....	...	...	...	(?)
<i>Neuropteris macrophylla</i> , Brongn. (?) ....	...	...	...	(?)
<i>Neuropteris tenuifolia</i> (Schl.) ? ....	...	...	...	(?)
<i>Neuropteris ovata</i> , Hoffm. ....	*	*		
<i>Neuropteris varinervis</i> , Banbury ....	*	*		
<i>Neuropteris gigantea</i> , Sternb. ....	...	*	...	*
<i>Neuropteris flexuosa</i> , Sternb. ....	*			
<i>Neuropteris Scheuchzeri</i> , Hoffm. ....	*	*	*	
<i>Linopteris Münsteri</i> (Eichw.) ....	...	...	...	*
<i>Linopteris obliqua</i> (Banbury) ....	...		...	*
<i>Calamites Suckowi</i> , Brongn. ....	*	(?)		
<i>Calamites undulatus</i> , Sternb. ....	*	(?)		
<i>Calamites Cisti</i> , Brongn. ....	(?)			
<i>Calamites Schützei</i> , Stur ....	*			
<i>Calamites varians</i> , Sternb. ....	...	...	...	*
<i>Calamites waldenburgensis</i> , Stur ....	...	...	...	*
<i>Calamocladus equisetiformis</i> (Schl.) ....	*	*	...	*
<i>Macrostachya infundibuliformis</i> (Brongn.) .	...	...	...	*
<i>Annularia radiata</i> , Brongn. ....	*	...	...	*
<i>Annularia sphenophylloides</i> (Zenker) ....	*			
<i>Annularia stellata</i> (Schl.) ....	*			
<i>Annularia galioides</i> (L. & H.) ....	...	...	...	*
<i>Pinnularia capillacea</i> , L. & H. ....	...	(?)		
<i>Sphenophyllum emarginatum</i> , Brongn. ....	*	*	...	*
<i>Sphenophyllum cuneifolium</i> (Stbg.) ....	...	...	...	*
<i>Lepidodendron fusiiforme</i> (Corda) ....	*			
<i>Lepidodendron lycopodioides</i> , Sternb. (Zeiller) ....	...	*		
<i>Lepidodendron ophiurus</i> , Brongn. ....	...	*		
<i>Lepidodendron Wortheni</i> , Lesq. ....	...	...	...	*
<i>Lepidostrobus variabilis</i> , L. & H. ....	...	*		
<i>Lepidostrobus anthemis</i> (König) ....	...	...	...	*
<i>Lepidophyllum lanceolatum</i> , L. & H. ....	*	*		
<i>Lepidophyllum intermedium</i> , L. & H. ....	*	*		
<i>Sigillaria Brardi</i> , Brongn. ....	...	*		

TABLE OF THE DISTRIBUTION OF THE PLANTS IN THE  
KEELE, ETC. GROUPS (*continued*).

SPECIES.	I. <i>Keele</i> <i>Group.</i>	II. <i>Newcastle</i> <i>Group.</i>	III. <i>Etruria</i> <i>Group.</i>	IV. <i>Black-</i> <i>band</i> <i>Group.</i>
<i>Sigillaria discophora</i> (König) .....	...	...	...	*
<i>Sigillaria ichthyolepis</i> , Sternb. ....	...	...	...	*
<i>Sigillaria ovata</i> , Sauveur .....	...	...	...	*
<i>Sigillaria tessellata</i> , Brongn. (?) .....	*	...	...	...
<i>Sigillaria</i> sp. ....	...	*	...	...
<i>Cyperites bicarinata</i> , L. & H. ....	*	...	...	...
<i>Stigmaria ficoides</i> (Sternb.) .....	*	*	...	*
<i>Cordaïtes angulosostratus</i> , Grand'Eury ...	*	...	...	...
<i>Cordaïtes borassifolius</i> (Sternb.) .....	*	...	...	*
<i>Cordaïtes principalis</i> (Germar) .....	...	*	...	...
<i>Trigonocarpus Parkinsoni</i> , Brongn. ....	...	...	...	*
<i>Rhabdocarpus sulcatus</i> (Presl) .....	...	*	...	...
<i>Artisia approximata</i> , Brongn. ....	...	(?)	...	...
<i>Artisia transversa</i> (Artis) .....	...	*	...	...
<i>Walchia imbricata</i> , Schimper .....	*	...	...	...

If the distribution of the species recorded from these four subdivisions be analysed, it will be found that of the 29 species observed in the Keele Group, all have previously been found in the Upper Coal-Measures, except *Lepidodendron fusiforme* (Corda), *Sigillaria tessellata*, Brongn. (?), and *Cordaïtes borassifolius* (Sternb.). The former, like a few other species of *Lepidodendron*, extends throughout all the divisions of the Coal-Measures, while the latter occurs at the very base of the Keele Group. *Neuropteris heterophylla*, Brongn., has not previously been found in Britain at so high a horizon, but it has been recorded by Prof. Zeiller from the Lower Series of the Upper Coal-Measures.<sup>1</sup> As yet, only a single specimen has been collected from the Keele Group. *Sigillaria tessellata* (?) is also new to the Upper Coal-Measures, for the specimens that I formerly recorded from the Radstock Series under this name are *Sigillaria cumulata*, Weiss.<sup>2</sup> It is also noticeable that there is an entire absence in the Keele Group of the small Sphenopterids and of the Sigillarians generally, which are so characteristic of the Middle Coal-Measures. These are always very rare in the Upper Coal-Measures, and their absence is one of the characteristics of that flora.

On the other hand, the Keele Group contains many most typical Upper Coal-Measure species, such as *Pecopteris arborescens* (Schl.), *P. cyathea* (Schl.), *P. unita*, Brongn., *Alethopteris aquilina* (Schl.),

<sup>1</sup> 'Bassin Houiller & Permien d'Autun et d'Épinac: Fasc. ii. Flore Fossile' pt. i (1890) p. 144 (Gîtes minéraux de la France).

<sup>2</sup> 'Die Sigillarien der preuss. Steinkohlengebiete: I. Die Gruppe der Favularien' Abhandl. d. Königl.-Preuss. geol. Landesanst. vol. vii (1887) p. 255 & pl. ix (3) figs. 33-36.

*A. Grandini* (Brongn.), *A. Serli* (Brongn.), *Odontopteris Lindleyana*, Sternb., *Neuropteris flexuosa*, Sternb., *N. ovata*, Hoffm., *N. Scheuchzeri*, Hoffm., *Annularia sphenophylloides* (Zenker), *A. stellata* (Schl.), *Sphenophyllum emarginatum*, Brongn., *Cordaïtes angulosostriatus*, Grand'Eury, and *Walchia imbricata*, Schimper; and, although some of these occur in lower horizons, still the Upper Coal-Measure horizon is where all of them attain their maximum development, and it is the horizon of which they are typical species. There can, therefore, be no doubt that the Keele Group must be classed as Upper Coal-Measures.

Passing to the plants recorded from the Newcastle-under-Lyme Group, we note that, of the 22 species observed, *Pecopteris arborescens* (Schl.), *P. cyathea* (Schl.), *Neuropteris flexuosa*, Sternb., and *N. ovata*, Hoffm., are typical Upper Coal-Measure species; but they are here associated with other species which are characteristic of the Middle and Lower Coal-Measures, such as *Pecopteris Miltoni* (Artis), which also is plentiful in the Upper Coal-Measures and frequent in the Middle Coal-Measures, *Neuropteris gigantea*, Sternb., *Lepidodendron lycopodioides*, Sternb. (Zeiller), *L. ophiurus*, Brongn., *Sigillaria Brardi*, Brongn., and *Cordaïtes principalis* (Germar). So there is clearly here a mixing of species, some of which are characteristic of the Upper, and others of the Middle, Coal-Measures.

From the Etruria-Marl Group only a single species, *Neuropteris Scheuchzeri*, Hoffm., has been collected. This is a very common Upper Coal-Measure plant; it is met with, however, though rarely, in the Middle Coal-Measures. The absence of plant-remains in this group is, nevertheless, not of so much importance, as a fair list has been obtained from the overlying Newcastle-under-Lyme Group and the underlying Blackband Group.

The Blackband Group has yielded 24 species. It contains a few which occur in the Upper Coal-Measures; these are *Pecopteris Miltoni* (Artis), which, as already mentioned, is also not uncommon in the Middle Coal-Measures, *Macrostachya infundibuliformis* (Brongn.), *Annularia sphenophylloides* (Zenker), also known from the Middle Coal-Measures, where it is, however, very rare, and *Sphenophyllum emarginatum*, Brongn., which is a very common Upper Coal-Measure plant; but the great majority of the species from the Blackband Group are Middle and Lower Coal-Measure forms. Of the characteristic Middle Coal-Measure plants, *Alethopteris valida*, Boulay, *Linopteris obliqua* (Bunbury), and *Sigillaria ovata*, Sauveur, may be mentioned. In this group, the Middle Coal-Measure plants become more strongly represented, and the Upper Coal-Measure plants are clearly reduced in number. In fact, from the Newcastle-under-Lyme Group to the base of the Blackband Group, a gradual change in the flora is taking place from below upwards. Upper Coal-

Measure species are beginning to appear, and the species which occur in the Middle Coal-Measures are gradually dying out. In such a list as that tabulated on pp. 316-17, the mere names of species do not fully represent this change; the plants of the Middle Coal-Measures become, however, rarer, not only in species, but in the number of the individual specimens found; and as these lower-horizon forms become rarer in individual quantity, the Upper Coal-Measure species become more plentiful in kind and numbers. The three subdivisions—the Newcastle-under-Lyme Group, the Etruria-Marl Group, and the Blackband Group, represent, therefore, a series of rocks, wherein the flora is a mixture of plants, some of which are characteristic of the Upper Coal-Measures, while others are characteristic of the Middle Coal-Measures.

It is consequently impossible to class these rocks, either with the Upper Coal-Measures above them, or with the Middle Coal-Measures upon which they rest, as they form a distinct botanical province, easily separated by their mixed association of species. It was for this group that I originally used the term of 'Transition Series'.<sup>1</sup>

When this term was proposed, I did not know the important place that this group would hold in the classification of the Upper Carboniferous; but, in recent years, the work of the Geological Survey of Great Britain, as well as evidence obtained from mining operations, has shown the Transition Series to be a widely-extended and important group, and one of great importance in determining the position of the more valuable underlying coal-bearing strata of the Middle Coal-Measures in our 'concealed' coalfields.

As, however, the term 'Transition Series' is a somewhat indefinite one, and naturally raises the question 'Transition between what'? I propose to substitute the term *Staffordian Series* for the inclusion of the Newcastle-under-Lyme Group, the Etruria-Marl Group, and the Blackband Group of North Staffordshire, as in that county these rocks have been worked out more fully in detail than in any other area where they occur. To Mr. Walcot Gibson we are largely indebted for the clear knowledge that we possess of the *Staffordian Series*, though others have helped in their elucidation, and of these, I would wish especially to refer to the work of Mr. T. C. Cantrill in the Enville and Forest-of-Wyre districts.<sup>2</sup>

For the Upper Coal-Measures I would propose the term *Radstockian Series*; for the Middle Coal-Measures, *Westphalian Series*, with which the flora of the Middle Coal-Measures appears to agree; and for the Lower Coal-Measures, the term *Lanarkian*

<sup>1</sup> Proc. Roy. Phys. Soc. Edin. vol. xii (1893-94) p. 228; also 'Additional Records & Notes on the Fossil Flora of the Potteries Coalfield' Trans. North Staffs. Field-Club, vol. xxxi (1897) p. 128.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. li (1895) pp. 528-48.

Series, as there is no area in which this series is better developed than in Lanarkshire.

This change of nomenclature is absolutely necessary, as the terms 'Upper,' 'Middle,' and 'Lower' Coal-Measures have been so loosely applied in the past, that in many cases these terms have only a local significance, having been applied to rocks of different ages in different districts. It is therefore necessary, in order to avoid further confusion, to introduce a new and distinctive terminology for the various divisions of the British Coal-Measures.

These proposed changes are shown in the following tabular form :—

COAL-MEASURES.

Upper Coal-Measures	=	{ Radstockian Series
Transition Series	=	{ (including the Keele Group).
Middle Coal-Measures	=	Staffordian Series.
Lower Coal-Measures	=	Westphalian Series.
(including the Millstone-Grit).	}	Lanarkian Series.

Before concluding this paper, I wish to refer to an interesting pit-sinking made at Bradford Colliery, Manchester, last year, at which the fossil plants were carefully collected from the shales associated with the Bradford Four-Foot Coal. A considerable number of specimens from these shales were submitted to me for examination by Mr. W. Hemingway and Mr. P. Whalley. A list of the plants from this sinking has already been published by Mr. John Gerrard, along with a section of the strata from which they were derived.<sup>1</sup>

I append a list of the species contained in the collections examined by me; they were derived from shales extending from 24 feet to about 321 feet above the Bradford Four-Foot Coal.

A comparison of this list with the species noted from the Blackband Group will show the great similarity of the two floras. There are still here two species, *Sphenophyllum emarginatum*, Brongn., and *Annularia sphenophylloides* (Zenker), characteristic of the Upper Coal-Measures, and some which are common to that horizon; but these are accompanied by an overwhelming proportion of species characteristic of the Middle Coal-Measures. The plant-evidence, therefore, indicates that the rocks from which the specimens came at Bradford Colliery belong to the Blackband Group of the Potteries Coalfield, and that the Bradford Four-Foot Coal occurs at the base of the Group, and would therefore occupy a position on or about the horizon of the Bassey-Mine Ironstone and Coal of the Potteries Coalfield.

<sup>1</sup> 'Notes on Fossils found above the Bradford Four-Foot Coal at Bradford Colliery, Manchester' Trans. Manch. Geol. & Min. Soc. vol. xxviii (1904) p. 555.

LIST OF FOSSIL PLANTS FROM BRADFORD COLLIERY, MANCHESTER, FROM SHALES  
EXTENDING FROM ABOUT 24 TO 321 FEET ABOVE THE BRADFORD FOUR-  
FOOT COAL.

### Staffordian Series.

(Subdivision, Blackband Group.)

- Sphenopteris artemisiaefolioides*, Crépin.  
*Sphenopteris Ascherborni* (Stur).  
*Sphenopteris dilatata*, L. & H.  
*Sphenopteris obtusiloba*, Brongn.  
*Oligocarpia Guthieri*, Göppert.<sup>1</sup>  
*Pecopteris Miltoni* (Artis).  
*Dactylothea plumosa* (Artis).  
*Mariopteris muricata* (Schl.).  
*Neuropteris cf. callosa*, Lesq.  
*Neuropteris heterophylla*, Brongn.  
*Neuropteris obliqua* (Brongn.).  
*Neuropteris rarinervis*, Bunbury.  
*Neuropteris Scheuchzeri*, Hoffm.  
*Neuropteris tenuifolia* (Schl.).  
*Linopteris Münsteri*, Eichw.  
*Aphlebia crispa* (Guthier).  
*Calamites Cisti*, Brongn.  
*Calamites ramosus*, Artis.  
*Calamites Suckowi*, Brongn.  
*Calamites undulatus*, Sternb.  
*Calamocladus charaeformis* (Sternb.).  
*Calamocladus equisetiformis* (Schl.).  
*Calamocladus grandis* (Sternb.).  
*Annularia radiata*, Brongn.  
*Annularia sphenophylloides* (Zenker).  
*Pinnularia capillacea*, L. & H.  
*Pinnularia columnaris* (Artis).  
*Sphenophyllum cuneifolium* (Sternb.).  
*Sphenophyllum emarginatum*, Brongn.  
*Lepidodendron lycopodioides* (Sternb.),  
 Zeiller.<sup>2</sup>  
*Lepidodendron rimosum*, Sternb.  
*Lepidostrobus variabilis*, L. & H.  
*Lepidophyllum lanceolatum*, L. & H.  
*Bothrodendron minutifolium* (Boulay).  
*Bothrodendron* sp. nov.  
*Sigillaria discophora* (König).  
*Stigmaria ficoides* (Sternb.).  
*Stigmaria ficoides*, var. *undulata*,  
 Göppert.

*Rhabdocarpus clavatus* (Sternb.).

1826. *Carpolithes clavatus*, Sternb. 'Essai  
d'un Exposé géogn.-botan. de la Flore du  
monde prim.' fasc. iv, p. xl & fasc. i,  
pl. vii, figs. 14 a-b.  
 1826. *Carpolithes lagenarius*, Sternb. *ibid.*  
fasc. iv, p. xli & fasc. i, pl. vii, fig. 16.  
 1855. *Rhabdocarpus clavatus*, Geinitz,  
'Versteinerungen d. Steinkohlenforma-  
tion in Sachsen' p. 42 & pl. xxii, figs. 12-  
14.

### Westphalian Series. (MIDDLE COAL-MEASURES.)

Species from shale immediately  
below the Bradford Four-Foot Coal,  
Bradford Colliery, Manchester:—

- Neuropteris gigantea*, Sternb.  
*Neuropteris tenuifolia* (Schl.).  
*Linopteris Münsteri* (Eichw.).  
*Linopteris obliqua* (Bunbury).  
*Calamocladus equisetiformis* (Schl.).  
*Lepidodendron lycopodioides* (Sternb.),  
 Zeiller.  
*Lepidostrobus anthemis* (König).  
*Lepidostrobus variabilis*, L. & H.  
*Lepidophyllum lanceolatum*, L. & H.

Species from shale 264 feet below  
the Bradford Four-Foot Coal, Brad-  
ford Colliery, Manchester:—

- Sphenopteris cf. schatzlarensis* (Stur).  
*Mariopteris muricata* (Schl.).  
*Linopteris obliqua* (Bunbury).  
*Calamites Cisti*, Brongn. (?).  
*Calamites undulatus*, Sternb.  
*Calamocladus equisetiformis* (Schl.).  
*Annularia sphenophylloides* (Zenker).  
*Sphenophyllum cuneifolium* (Sternb.).  
*Sphenophyllum majus*, Brongn. (?).  
*Lepidophloios* sp.  
*Lepidostrobus anthemis* (König).

### DISCUSSION.

Dr. WHEELTON HIND said that he would enter a *caveat* against  
the adoption of the new classification of the Coal-Measures proposed  
by the Author. The study of palæobotany was of the highest  
importance, but plants were not the only fossils found in the Coal-  
Measures; the evidence of all the fossils alike, fishes and mollusca

<sup>1</sup> The *Discopteris* (?) Ralli of Mr. Gerrard's list, *op. cit.* p. 561.

<sup>2</sup> As figured by Prof. Zeiller, in his 'Description de la Flore fossile du Bassin  
houiller de Valenciennes' (Gîtes minéraux de la France) 1886, pl. lxi, figs. 2-3  
& pl. lxx, fig. 1.

as well as plants, must be taken into account, and the story told by each must agree in the main details, else classification, founded on the study of one group alone, would probably lead to erroneous results. It was difficult to criticize a paper from a mere abstract, but the questions which at once occurred to him were:—‘How sharp are the proposed lines of subdivision? Are they exact and absolute? Can they be traced from coalfield to coalfield? Are they of practical utility?’ The speaker felt strongly that there was no good reason for taking the Bassey-Mine Ironstone as the base of a subdivision; a similar flora and fauna occurred both above and below this horizon, and he (the speaker) had made his subdivision at the horizon of the Gubbin Ironstone, where *Anthracomya Phillipsii* came in for the first time, on lithological grounds.

He entirely objected to the term *Staffordian*, for two reasons. It was unnecessary, for there were already in use the terms *Etruria Marls* and *Blackband Series*, which were more topical and exact. As the *Blackband Series* was not developed in South Staffordshire, the term *Staffordian* was inexact and included too much. Indeed, used in the Author’s sense, it ought to be *North Staffordian*.

The speaker also entered a protest against the use of the terms *Westphalian* and *Lanarkian*. There was neither unconformity nor faunal break in the Coal-Measures of the Midlands, and any subdivision must be therefore wholly artificial and empirical. Further, he did not believe that the *Lanarkshire Coalfield* was merely the homotaxial equivalent of the lower part of the *Staffordshire Coal-Measures*. The molluscan fauna strongly contradicted such an assumption. The heresy of the subdivision into *Upper*, *Middle*, and *Lower Coal-Measures* had taken a long time to kill, and the speaker failed to see that the Author’s proposition had any more real basis. At any rate, in *North Staffordshire* there was no stratigraphical or faunal evidence in favour of drawing a subdivision at the *Ash Coal*.

Mr. STRAHAN agreed with the previous speaker in deprecating the introduction of the new names suggested for the subdivisions of the Coal-Measures. They were inferior to the old names, in being in no way self-explanatory, while they placed an unnecessary tax upon the memory.

It had been said during the evening that horizons in the Coal-Measures could be determined both by plants and lamellibranchs, but he would point out that a problem of the greatest economic importance, which had exercised the minds of the Coal-Commissioners of 1871 and of mining engineers ever since, remained still unsolved. The difficulty lay in correlating the Measures proved at *Bradford* with those at *Astley*, and in determining the relative positions of the *Bradford Four-Foot Seam* and the *Worsley Four-Foot Seam*. There were more than 3000 feet of strata in question. So far, they had been told that the *Bradford Seam* was associated with plants of ‘*Transition*’ (*Staffordian*) type, and a correlation was suggested



with the Bassey Mine of Staffordshire, but none was attempted with its immediate neighbour, the Worsley Seam. As a fact, when the question came up for consideration by the Royal Commission of 1905, no help was forthcoming from palæontologists. The Author's views with respect to the general distribution of the plants and the absence of hard-and-fast lines between the floras seemed to be quite in accordance with facts, and the paper was an important addition to the Author's previous contributions on the subject.

Mr. J. T. STOBBS said that, as a worker among the Coal-Measures, who collected plants, shells, and fishes, he felt compelled to protest against the proposed general classification of the Coal-Measures for the following reasons:—(1) It was based on partial evidence, and neglected the valuable aids to be derived from the fossil mollusca and fishes. Above the base of the Etruria Series, no doubt that, together with the evidence of thin entomostracan bands, the plant-evidence was of paramount importance; but, below that line, he stated without hesitation, after a daily experience extending over several years, that the lamellibranchs were of greatest use for the correlation of the Measures. (2) It was unnecessary: all that the paper demonstrated was the accuracy and soundness of Mr. Walcot Gibson's work in subdividing the Upper Measures of the Midland Coalfields: to add the term Radstockian to that of Keele was quite unnecessary. (3) The upper and lower limits of the 'Staffordian' were very definite zoological lines, and it was more than doubtful that they coincided with so sweeping a change in the fossil flora. The Bassey-Mine Ironstone was not a well-chosen base, as the plants from beds below were similar to those in the overlying marls. Could the Author have distinguished the Keele Series from the Newcastle Series, simply by the aid of the plant-evidence which he had examined from the Newstead boring?

Mr. WALCOT GIBSON stated that the terminology suggested by the Author was founded on strictly-palæobotanical lines, and palæobotanists must decide as to its value. For local purposes of the correlation of one seam of coal with another, the plant-evidence was of less value than the shells; but instances had recently occurred when the plant-remains had proved of great service, in determining whether a red sandstone reached in a boring belonged to an horizon above the Productive Measures or to one wholly below them.

13. *On the SPORANGIUM-LIKE ORGANS of GLOSSOPTERIS BROWNIANA, Brongn.* By E. A. NEWELL ARBER, M.A., F.L.S., F.G.S., Trinity College, Cambridge; University Demonstrator in Palæobotany. (Read February 1st, 1905.)

## [PLATES XXX &amp; XXXI.]

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## I. INTRODUCTION.

*GLOSSOPTERIS* is now among the most familiar of all fossil plants. The tongue-shaped fronds of this genus, with their reticulate lateral nervation, are exceedingly characteristic of the Permian-Carboniferous rocks of India, Australasia, and Southern Africa, and occur also in the Permian of Russia, and in beds of Rhætic age in Tongking and China. So great is the abundance of these fern-like leaves in the Lower Gondwana Series of India, and its homotaxial equivalents in the Southern Hemisphere, that this plant has given its name to the flora of that former continental region.

Although a very large number of *Glossopteris*-fronds have been described by different authors, it is only within the last few years that we have learnt anything as to the general habit of this plant. We are chiefly indebted to the researches of Prof. Zeiller, of Paris, for progress in this respect. It has now been ascertained that this plant was heterophyllous,<sup>1</sup>—a fact which was first suggested by McCoy in 1847.<sup>2</sup> In addition to the larger and often tongue-shaped fronds, much smaller leaves, generally spoken of as scale-fronds, were borne on a rhizome-like stem, which has been long known under the name of *Vertebraria*.<sup>3</sup> The nervation of the scale-fronds resembles that of the larger leaves, except that there is no midrib. In shape they are, as a rule, ovately triangular, pointed at the apex, and strongly concave. An average specimen measures 1½ centimetres or more in length.

<sup>1</sup> Zeiller (96<sup>1</sup>) p. 365. [Numerals in parentheses after authors' names refer to the dates in the Bibliography, § viii, p. 336.]

<sup>2</sup> McCoy (47) p. 151; see also Arber (02) p. 9.

<sup>3</sup> Zeiller (96<sup>2</sup>) and Oldham (97).

Up to the present time we are without any definite information as to the fructification, and consequently we know nothing of the true systematic position of this genus. It is admitted that the sporangia of this plant have never been observed.<sup>1</sup> Several authors, however, have drawn attention to certain features occasionally exhibited by the larger fronds, which they have interpreted as indications of the position of sori. The evidence on this point will be discussed at a later stage in this paper (p. 332).

Some months ago, when cataloguing the large collection of fronds of *Glossopteris* in the Geological Department of the British Museum (Natural History), I discovered some specimens from New South Wales exhibiting numerous and well-preserved scale-leaves, with which were associated groups of minute bodies almost invisible to the naked eye. On microscopic examination these proved to be sac-like organs which, so far as I am aware, are new to science.

These bodies will be fully discussed here, and it will be shown that they resemble the sporangia of certain living and extinct plants closely enough to permit us to speak of them as sporangium-like organs. The specimens which exhibit these sac-like structures are unfortunately few in number; and despite the fact that similar, but less perfect, examples have since been discovered in the collections at Cambridge, the material available in the museums of this country for the study of these new organs is at present too limited to permit of a complete or final elucidation of their nature or structure. While, therefore, some of the conclusions expressed here are to be regarded as provisional, pending the discovery of further specimens, there is reason to believe that the present evidence is sufficiently strong to show that these bodies, whatever may be their precise nature, may be attributed with confidence to the fossil plant known as *Glossopteris Browniana*, Brongn.

## II. DESCRIPTION OF THE SPECIMENS.

Before describing in detail the structure and possible nature of these sac-like organs, a brief description may be given of the specimens on which they occur. In no case is the anatomical structure preserved. The sacs are preserved merely as casts or impressions, and, as such, the preservation is often exceedingly perfect.

V. 7202, in the Geological Department, British Museum (Natural History).—This specimen is a nearly-square piece of pinkish shale, obtained from Port Stephens (New South Wales), and belongs to the Odinheimer Collection, which was transferred to the Museum about the year 1859. Typical fronds of *Glossopteris Browniana* occur on both sides of the specimen; in fact, the rock appears to consist largely of impressions of these leaves. Several well-preserved scale-fronds are seen on one surface, and closely associated with them are groups of minute prominences

<sup>1</sup> Seward (97<sup>1</sup>) p. 319.

scarcely visible to the naked eye. These are the clusters of sporangium-like bodies. Enlarged drawings of some of these organs are shown in Pl. XXX, figs. 1 & 3 & Pl. XXXI, fig. 3.

The scale-fronds have a bluish tint, which is a natural feature. A group of these fronds, somewhat flattened, occurs at one angle of the specimen, of which the largest is 1.7 centimetres long, and about 1 cm. broad at its widest part. Close to them, a considerable number of the sporangium-like bodies are scattered over the surface of the shale, some of which are represented in Pl. XXX, fig. 1, and Pl. XXXI, fig. 3. Smaller portions of scale-leaves are also found, some of which appear to show the prints, or scars of attachment of the sporangium-like bodies, and some fragments of these organs possibly still in continuity. The best example is figured in Pl. XXX, fig. 4. Several other groups of these organs occur on the same specimen, in close proximity to scale-leaves, of which that figured in Pl. XXX, fig. 3 is a typical instance.

V. 7211 is a similar specimen, in the same collection, and from the same locality.—It is a triangular piece of pinkish scale, on which are to be found twenty or more examples of the scale-fronds, and a few fragments of the larger fronds. Associated with the scale-leaves, numerous scattered groups of the sporangium-like bodies may be observed, of which two specimens are figured in Pl. XXX, fig. 2 and Pl. XXXI, fig. 4. There also appears to be some evidence, though not very distinct, of scars, possibly the scars of attachment of these organs, on some fragments of the scale-fronds.

39,149 is another, and similar piece of shale, in the same collection, and from the same locality, which shows several, nearly-perfect specimens of the larger fronds, and a good example of a strongly-convex scale-frond, as well as other less perfect fragments of the scale-leaves. The groups of sporangium-like bodies are fairly well-preserved, but are not perhaps quite so satisfactory as in the previous specimens. In one instance, a small portion of a scale-frond appears to exhibit one or two scars, possibly the prints of attachment of these organs, and also several sporangium-like organs have the appearance of being still in continuity, but, in this case, the evidence is less trustworthy than that of the previous specimen (Pl. XXX, fig. 4). Many of these sporangium-like bodies, in this as in other specimens, have opened or dehisced (Pl. XXXI, fig. 1). The inner surface is strongly concave, and may be distinguished from the outer by the fact that the cell-walls of the inner limiting-layer are much less conspicuous. The detached sporangium-like organs often occur in groups (Pl. XXXI, fig. 2), arranged as if several were borne together in a cluster or sorus.

No. 65 in the Sedgwick (Woodwardian) Museum, Cambridge (Foreign Plant-Collection), was obtained from the

Newcastle Series of New South Wales, and belongs to the Clarke Collection presented to the Museum in November 1844.—This specimen is especially interesting, for M'Coy,<sup>1</sup> in 1847, first ascertained from it the existence of the scale-fronds of *Glossopteris*. Several good examples of the scale-leaves are shown, some of which measure from 1.5 to 2 centimetres or more in length. Near one of them, a group of detached sporangium-like bodies occurs, similar to those seen in the preceding specimens, but not quite so well preserved.

No. 104 is a specimen recently acquired by the Sedgwick Museum, from Adamstown (New South Wales).—The rock is largely composed of felted masses of the fronds of *Glossopteris*, with an occasional scale-frond. Near one of the scale-fronds, a few, rather indistinct impressions of these sporangium-like bodies may be seen.

No. 446, in the Bunbury Collection, in the Botany School, Cambridge, was obtained from the Hunter River at Newcastle (New South Wales).—A portion of this specimen has recently been figured by Mr. Seward,<sup>2</sup> to whom I am indebted for an opportunity of examining the material in the Bunbury Collection. The rock consists of a pinkish shale, in many respects similar to the specimens in the British-Museum Collection, and, like those specimens, was originally acquired through the Geological Survey about the year 1859. In addition to the scale-fronds figured by Mr. Seward, other and less perfect examples occur; and, in one case, where a portion of the highly-convex scale-frond has been broken away, a group of these sporangium-like bodies is exposed, lying beneath the scale-leaf. One of these sacs shows the neck-like extremity very clearly. A few other groups can be made out, but they are not distinct, nor is the preservation very good.

### III. THE MORPHOLOGY OF THE SPORANGIUM-LIKE ORGANS.

From a study of the groups of detached sporangium-like bodies occurring on the specimens above described, the following points in their morphology can be determined. They are somewhat elliptical in shape, tapering at either extremity (Pl. XXX, figs. 1–3 & Pl. XXXI, figs. 2–4). They measure from 1.2 to 1.5 millimetres along the major axis, and their greatest breadth varies from .6 to .8 mm. The shape of these bodies naturally differs somewhat, according to the particular manner in which they have come to rest upon the clay, and according to the aspect which they present (Pl. XXXI, figs. 3 & 4). In some examples, one extremity appears to be bent into a short neck-like prolongation, measuring about .2 mm. in length (Pl. XXXI, fig. 3 at *a*, & Pl. XXX, fig. 3 at *x*), and thus the whole body resembles somewhat a retort in shape. In others, the neck is flattened on the main portion of the body,

<sup>1</sup> M'Coy (47) p. 151; Arber (02) p. 9.

<sup>2</sup> Seward (97<sup>1</sup>) p. 318 & pl. xxiii, fig. 1.

while in others again no such neck can be recognized (Pl. XXX, fig. 1 & Pl. XXXI, fig. 4).

In many of the specimens, especially those in which the preservation is particularly good, the cell-walls of the outer limiting-layer of the sac are conspicuous (Pl. XXX, figs. 1-2 & Pl. XXXI, figs. 3-4); and the sac has the appearance of being strongly striated in the direction of its greater axis. These walls are united by very short cross-walls, placed more or less obliquely, and thus the cells are rhomboidal in shape, and of much greater length than breadth (Pl. XXXI, fig. 4). At the apex of the sac, which is probably the extremity opposite to the neck, the cells appear to be somewhat smaller and narrower.

Such evidence as there is to be found in these specimens, points to the fact that these sporangium-like bodies were probably attached by the neck-like prolongation. In the few, and perhaps not wholly trustworthy instances, in which fragments of these organs seem to be still in continuity with the scale-leaves (Pl. XXX, fig. 4), this appears to be the case; and supplementary evidence may be found in the way in which the detached bodies are often grouped together, which distinctly suggests in many cases an aggregation into sori, like the sporangia of many fossil and recent ferns. In Pl. XXX, fig. 3, portions of four of these bodies are seen, in one of which ( $\alpha$ ) the neck is evident, and is turned towards what was probably the common point of attachment of all the organs of this group. Another such group, similarly arranged, is figured in Pl. XXXI, fig. 2.

The evidence for the attribution of these sac-like structures to *Glossopteris Browniana* will be dealt with in the following section of this paper. It will be shown that there are some grounds, although not as conclusive as one could wish, for the view that these sporangium-like organs were borne on the concave surface (possibly the lower surface) of the scale-leaves.

These organs are not solid bodies. They were undoubtedly sac-like structures, and, in the living state, must have contained something. Their appearance is essentially that of a distended sac (Pl. XXX, fig. 2). Further, they seem to have opened or dehisced longitudinally, that is, in the direction of the major axis (Pl. XXXI, fig. 1). The exact mode of dehiscence cannot be ascertained. The splitting may have begun first at the apex (Pl. XXX, figs. 1 & 2), but this is not quite certain. The evidence is, however, sufficient to show that such dehiscence was, in all probability, a natural feature at a certain stage in their development. The wall of the sac, so far as one can judge from specimens in which the anatomical structure is not preserved, was probably more than one layer of cells in thickness. Not only does it appear to be comparatively thick (Pl. XXX, fig. 1  $\alpha$ ), but the cell-walls of the inner limiting-layer are much less conspicuous than those of the outer, and in many cases can hardly be distinguished (Pl. XXXI, fig. 1). The three sporangium-like bodies figured in Pl. XXXI, fig. 1 have probably all dehisced, and are viewed from

the inner surface, as is shown by the shape and concave surface, as well as by the much less prominent character of the cell-walls.

Unfortunately, no trustworthy evidence can be obtained as to the contents of these sacs. In cases where the splitting appears to have just begun, a solid mass of grey material projects (Pl. XXX, fig. 2 a), but the nature of the contents cannot be distinguished. In other examples (Pl. XXXI, fig. 1) a few very minute bodies, dissimilar to the matrix of the rock, can be seen on the inner surface of the fully-opened sacs, but these afford no evidence of any value on this point.

#### IV. THE EVIDENCE FOR THE ATTRIBUTION OF THE SPORANGIUM-LIKE ORGANS TO *GLOSSOPTERIS*.

There would seem to be little doubt that these sporangium-like organs belong to *Glossopteris Browniana*, although the evidence is, in part, indirect. These sac-like bodies have never been observed, except in close relationship to the scale-leaves of *Glossopteris*. The fact that specimens, which do not show the scale-fronds, are also wanting in respect to these retort-like sacs is especially significant, and argues a connection between these two organs. Examples of the scale-fronds are comparatively rare, both at the British Museum and at Cambridge, and are probably not very abundant, at present, in any foreign collection. This fact probably explains why these sporangium-like organs have remained unobserved until the present day, although many authors (including Bunbury, Feistmantel, Zeiller, and others) have closely studied the larger fronds of this genus, with the view of obtaining evidence as to the fructification of *Glossopteris*. I have, myself, recently had occasion to examine carefully the considerable collections of the larger fronds in the British and Sedgwick Museums, which include the best examples in this country, but I have not, in any single instance, observed these sac-like bodies on specimens which do not also show scale-leaves in close proximity.

As a further test of the value of this evidence, I asked Prof. Zeiller to search for these organs among the specimens of *Glossopteris* from the Transvaal, which he described in 1896. This he very kindly undertook to do, and was successful in finding an example, which again occurred in close proximity to a scale-leaf.<sup>1</sup> I may here express my thanks to him for his kindness in this matter.

The evidence, detailed above, is admittedly of a negative nature, but it is now recognized that, as such, it is not without weight, when based on a sufficiently-large number of observations. In addition, there is also some direct evidence to be gained from these specimens. It has been already pointed out that, in a few cases, none of which perhaps are so conclusive as one could wish,

<sup>1</sup> The sac in question occurs on the left-hand border of the scale-leaf figured by Prof. Zeiller, (96<sup>1</sup>) pl. xvi, figs. 13 & 13 a.

some of the fragments of the scale-leaves show what may possibly be interpreted as the scars of attachment of these sporangium-like bodies, and also portions of the sac-like bodies themselves, which have the appearance of being still in continuity. The best example is that seen enlarged 15 times in Pl. XXX, fig. 4. It consists of a small portion of a scale-leaf, which, at the lower extremity, is obscured by a confused mass of these sac-like bodies resting upon it. The leaf is undoubtedly a scale-leaf, as is shown by the absence of a midrib, and the nervation, which, although somewhat faint, is that of a *Glossopteris*. Several oval scars are seen (at *a, b, c*), and in two cases (*b* and *c*) fragments of the sacs are apparently still in continuity. No great weight is, however, laid on the latter point, for, in such impressions, it is often a matter of the greatest difficulty to show that features which suggest continuity may not be equally well explained on the grounds of chance association. Similar, but less clear evidence is to be gained from fragments of some of the other scale-leaves exhibited by these specimens.

In this connection, the absence of any trace of the rhizome, *Vertebraria*, in association with these organs is remarkable, and the probability is thereby increased that these sac-like bodies were not borne on a stem-structure. There is also no suggestion of any aggregation into a strobilus-like arrangement, however lax.

This evidence, in addition to that of the constant association of these sac-like bodies with the scale-fronds already discussed, while it may not be quite conclusive as to the exact manner in which these organs were borne, is, I think, sufficient to place beyond doubt their attribution to the fossil *Glossopteris Browniana*.

#### V. THE MORPHOLOGICAL NATURE OF THE SPORANGIUM-LIKE ORGANS.

There remain to be discussed the nature and probable function of these sac-like bodies.

It would seem certain that, whatever may be the true solution of this problem, these organs are not ramenta or chaffy scales, such as occur on many ferns, both living and extinct. Their hollow, sac-like structure, as well as other features of their morphology, is totally opposed to any such inference.

On the other hand, there is much to be said in favour of the conclusion that these organs were true sporangia. We have seen that there is some evidence for the provisional view, that they were borne on the scale-fronds of *Glossopteris Browniana*, that is on a foliar organ. The aggregation of these sac-like bodies into groups, recalling the sori of the true Ferns, lends further support to this argument. In their structure also, these bodies exhibit characters common to the sporangia of both living and extinct plants, although, so far as I am aware, they do not agree so closely with any one type of sporangium as to remove at once all doubt concerning their real nature.

In size, they are neither larger nor smaller than certain fossil sporangia. They agree very nearly in this respect with those of



*Sphenophyllum*, as described by Prof. Zeiller.<sup>1</sup> They are somewhat larger than the sporangia of *Discopteris*,<sup>2</sup> but not so large as those of *Zygopteris*.<sup>3</sup>

There is also a certain similarity in shape and structure with the sporangia of *Discopteris Rallii*, Zeill., and of *Sphenophyllum cuneifolium* (Sternb.); although in both cases such sporangia exhibit features which are not present in the specimens described here. The shape of the cells of the outer limiting-layer is, however, an especially-conspicuous character in common. An even closer comparison may be found in the microsporangia of recent Cycads, such as *Stangeria paradoxa*, Th. Moore (compare, in Pl. XXXI, fig. 4 with fig. 5: the latter representing the Cycad-sporangium), which are neither dissimilar in size, shape, nor mode of dehiscence, and on the whole agree better with these new specimens than any other type of sporangium with which I am acquainted.

It has been pointed out that the wall of these sac-like organs was probably more than one layer in thickness, so far as it is possible to judge of such a character in cases in which the anatomical structure is not preserved. This feature is also common to fossil sporangia, such as those of *Zygopteris*, and many others.

Further, if these bodies are rightly interpreted as sporangia, then the sporangium of *Glossopteris* was exannulate, and in this respect resembled a very large proportion of Palæozoic fern-like plants. If an annulus had been present; or if these sac-like bodies had been united into synangium-like groups; or, again, if the anatomical structure had been preserved, their morphological nature would have been obvious. But the fact that no annulus is present does not militate against the sporangial nature of these new specimens. In addition to the Palæozoic plants, some recent Ferns, the Marattiaceæ in part, are exannulate, and the microsporangia of recent Cycads, which these bodies so closely resemble, are also probably without a true annulus.<sup>4</sup>

We have a further confirmation of this view in the fact that these sac-like bodies tend to open longitudinally, in a manner somewhat closely similar to the microsporangia of such a Cycad as *Stangeria*, or the sporangia of the recent fern *Angiopteris*. That these sporangium-like bodies dehisced appears to be abundantly evident from these specimens, and their manner of dehiscence is not unlike that of many Palæozoic fern-like plants. Thus, there seems to be little doubt, in the face of the whole of this evidence, that the probable nature of these sac-like bodies was that of a sporangium. A sporangium, however, should contain spores, but unfortunately I have so far failed to obtain any evidence as to the contents of these sacs. It is quite possible that the spores may have been very minute. Certainly, if they were as small as the pollen-grains of *Stangeria*, we should be hardly able

<sup>1</sup> Zeiller (93) p. 21.

<sup>2</sup> Zeiller (99) p. 18 & text-figs. 3-4.

<sup>3</sup> Scott (00) p. 288.

<sup>4</sup> Lang (97) p. 431 & (00) p. 297; Treub (81) pl. iii, fig. 2.

to identify them in such impressions. Even in petrified material, spores cannot always be found in certain types of sporangia. In the absence of any recognition of spores, and in view of the somewhat provisional nature of some of the other conclusions arrived at, I prefer to speak of the sac-like bodies for the present as sporangium-like organs. On the evidence presented here, I regard their sporangial nature as highly probable, and I am unable to suggest any alternative hypothesis.

#### VI. HISTORICAL SKETCH OF THE PRESENT EVIDENCE AS TO THE FRUCTIFICATION OF *GLOSSOPTERIS*.

The conclusion that the organs described here are probably, though not beyond all doubt, of the nature of sporangia, and therefore the whole or part of the reproductive apparatus of the sporophyte of *Glossopteris*, calls for some brief remarks on the numerous views which have been already expressed by different authors concerning the subject of the fructification of this plant. As has been already stated, no one has so far recognized any bodies that could be regarded as the sporangia of *Glossopteris*, although several have figured features which have been considered as indicative of sori.

The sori of *Glossopteris* have been described by one or other writer in every possible relationship to the larger fronds, and to them alone. Mr. W. Carruthers<sup>1</sup> has detected what he believed to be sori on some fronds from Queensland, which he describes as

'indications of fruit, in the form of linear sori running along the veins, and occupying a position somewhat nearer to the margin of the frond than to the midrib.'

Such sori occur in several recent ferns, *Antrophyum reticulatum*, Kaul., among others, which possesses a frond not unlike that of *Glossopteris*. It is, however, very doubtful whether the sori were borne on the secondary nerves in the latter genus. The preservation of some of the fronds from Tasmania and New South Wales is so exceptionally good, that it is almost certain that such sori (if they had existed) would have been detected long ago.

Feistmantel<sup>2</sup> described and figured a number of fronds which he regarded as fertile. Among these, one of the linear type, *Glossopteris angustifolia*, showed a narrow portion of the lamina at the margin, which was not traversed by the lateral veins, and this Feistmantel regarded as indicative of marginal sori. It is hardly necessary to point out that this alone is not trustworthy evidence in favour of such a conclusion.

But by far the most numerous examples, figured by various authors as possibly fertile fronds of *Glossopteris*, are those in which circular or oval spots, patches, or holes occur in the lamina of the frond, often of considerable size, and sometimes arranged more or less parallel to the midrib.

<sup>1</sup> Carruthers (72) p. 354.

<sup>2</sup> Feistmantel (80) p. 106 & pl. xxxix A, figs. 1, 1a, 2.

Brongniart,<sup>1</sup> himself, first pointed out the occurrence of patches of this type on the frond named by him *Glossopteris Browniana* var. *indica*, which he stated were probably indications of sori.

In 1861, Bunbury<sup>2</sup> figured further fronds from India of a similar nature, which he regarded with little doubt as indicating sori, although he admitted that he could find no organic structure. Mr. Seward<sup>3</sup> has recently re-examined Bunbury's specimens, which are in the Museum of the Geological Society of London, and has concluded that

'it may be that the patches are merely holes in the leaf, and not the impressions of sori.'

With this conclusion I quite agree, having also had an opportunity of seeing the specimens in question.

We may pass over the figure given by Ralph Tate<sup>4</sup> in 1867, under the name of *Rubidgea Mackayi*, which was supposed to be a fertile frond of a somewhat similar kind, since the type-specimen has never been in this country, nor examined by a competent authority. His figure is simply a reproduction of a sketch sent from South Africa, and now in the Museum of the Geological Society.

Feistmantel<sup>5</sup> figured fronds of *Glossopteris Browniana* and *Gl. indica*, showing features which he interpreted as indications of sori, but most of these would appear to be holes in the fronds, somewhat irregularly arranged on either side of the midrib, and very unequal in size.

Prof. Edgeworth David<sup>6</sup> described in 1891 a *Glossopteris* from the Greta Coal-Measures at Richmond Vale, near Maitland (New South Wales), showing dark oval-shaped bodies symmetrically arranged on the leaves, which might possibly represent the fructification. Mr. Etheridge, jun., however, who also examined the specimens, regarded the evidence in this case as inconclusive.

Somewhat similar specimens, also from New South Wales, were described and figured by Mr. John Mitchell<sup>7</sup> in 1893, in which three suboval, convex impressions occurred between the midrib and the margin, which were regarded as sori. In 1894, Mr. Etheridge, jun.,<sup>8</sup> discussed at some length the evidence as to the fructification of this genus, and, like Feistmantel,<sup>9</sup> laid perhaps more stress on this character, from a systematic standpoint, than the present position of our knowledge altogether justifies. In 1896, Prof. Zeiller<sup>10</sup> figured an apical portion of a frond of *Glossopteris angustifolia*, which seemed to show indications of sori on each side of the

<sup>1</sup> Brongniart (28) p. 224 & pl. lxii, fig. 2.

<sup>2</sup> Bunbury (61) p. 327 & pl. viii, fig. 1.

<sup>3</sup> Seward (97<sup>2</sup>) p. 180.

<sup>4</sup> Tate (67) p. 141 & pl. v, fig. 8.

<sup>5</sup> Feistmantel (80) pp. 97-98, 101 & pl. xxvi A, figs. 1-4, pl. xxvii A, figs. 1, 2, 5; *id.* (82) p. 32 & pl. xxi, figs. 13-14.

<sup>6</sup> David (91) pp. 424-25.

<sup>7</sup> Mitchell (93) p. 377 & text-fig.

<sup>8</sup> Etheridge (95) pp. 236, etc.

<sup>9</sup> Feistmantel (80) & (82).

<sup>10</sup> Zeiller (96<sup>1</sup>) p. 369 & pl. xviii, fig. 3.

median nerve. These patches are oval in shape and fairly well-defined, consisting of three or four slight depressions, which recall the sori of certain recent Polypodioids.

On the other hand, in the following year, Mr. Seward figured a specimen very similar to Prof. Zeiller's leaf, also from South Africa, which showed irregular elliptical or circular holes in the frond instead of sorus-like patches. Mr. Seward has called attention to the

'danger of attaching any great importance to characters of this kind.'

In the same year, he<sup>2</sup> also concluded a summary of the present evidence with the following remarks :

'On the whole, it would seem the safer course to admit that as yet no trustworthy example of a fertile *Glossopteris*-frond has been recorded from either India or Australia, and we have certainly no data on which any classification can be legitimately founded.'

Before leaving this subject, I may point out that a provisional suggestion of my own,<sup>3</sup> put forward in 1903, when describing some *Glossopteris*-fronds from Rhodesia, is probably quite misleading. Although I am still unable to account satisfactorily for certain features presented by the fronds in question, I do not now regard them as in any way connected with the fructification, as I then suggested.

Such, so far as I am aware, is practically all the evidence that we have at present on the subject of the fructification of *Glossopteris*. No organ of the nature of a sporangium has ever been described. The evidence of the position of sori has been gathered from spots, patches, or holes occurring on the lamina of certain of the larger fronds. I have myself observed such occurrences, but in no case have I obtained any real evidence that they are in any way indicative of sori. In order to ascertain whether such holes and patches occur among recent ferns of similar habit, I have looked through the specimens in the Cambridge herbarium, and I have found that holes are far from rare in such fronds. Spots or patches also occur, here and there, on fronds, which are quite without any connection with the fructification. A particularly-good instance was found in a sterile frond of *Acrostichum lanceolatum*, Hook., which corresponds very closely in habit with *Glossopteris Browniana*, where both holes and well-marked spots, similar in appearance to those mentioned above, were observed: the latter being due to either fungal or insect-agency.

## VII. GENERAL CONCLUSIONS.

From a consideration of what has previously been contributed on the subject of the fructification of *Glossopteris*, we have seen that the evidence that sori are to be found on the larger fronds is not, at present, satisfactory. The suggestion, made here, that the

<sup>1</sup> Seward (97<sup>1</sup>) p. 320 & pl. xxi, fig. 1.

<sup>2</sup> Seward (97<sup>2</sup>) p. 181.

<sup>3</sup> Arber (03) pp. 288-89.

sporangia—if these retort-shaped bodies are really of this nature—were possibly borne on the smaller scale-fronds, is a new one, and does not in any way involve the larger fronds. It has this merit, that definite organs, which in size, shape, and structure have been shown to be not unlike the sporangia of certain recent and Palæozoic plants, and are also aggregated into sori, are described for the first time. Although the final proof of the sporangial nature of these organs—the recognition of spores—is wanting, the resemblance is sufficiently striking to warrant the term sporangium-like organs.

If, as is suggested here provisionally, it should eventually prove that these bodies are true sporangia, then it would seem to be impossible to regard *Glossopteris* as a Fern allied to any recent family of the true Ferns. It may have belonged to some extinct race of Ferns, but it must be borne in mind that, although this plant has been regarded as a Fern by most of those who have studied it in the past, this view has been based on the similarity of habit and leaf-form, rather than on any real knowledge of the fructification. While it is true that the fronds of *Glossopteris* agree fairly closely with those of certain species of the recent ferns *Drymoglossum*, *Acrostichum*, *Onoclea*, and others, as Prof. Zeiller<sup>1</sup> and Mr. Seward<sup>2</sup> have pointed out, they are quite unlike any recent family of Ferns in the characters of their sporangia. Dimorphic ferns exist, in which the fertile fronds are smaller than the sterile, and in which the lamina is not markedly reduced, as for instance, among others, *Acrostichum villosum*, Sw.<sup>3</sup> But in the case of *Glossopteris*, the sporangia, if such be the real nature of these sac-like bodies, would seem to agree more closely with the microsporangia of a Cycad than with the sporangia of any living fern.

Or again, even if the sporangial nature of the organs described here be admitted, it may be doubted whether our knowledge of the affinities of *Glossopteris* is thereby much advanced. Such evidence as there is would tend to remove the genus from proximity to the recent Ferns, despite its fern-like habit, and it has yet to be ascertained whether *Glossopteris* was an isosporous or a heterosporous plant. In the latter event, these sac-like bodies are probably microsporangia. At present, however, there is no means of solving this problem.

There is still a further possibility to be borne in mind. It has been recently shown that some of the most fern-like of all the fronds of the Coal-Measures did not belong to the true Ferns, but to a race of seed-bearing plants, for which the name Pteridospermeæ<sup>4</sup> has been recently suggested. Some of the British Sphenopterids and Neuropterids<sup>5</sup> are of this nature. There is at least the possibility that *Glossopteris* may eventually prove to be a seed-plant, in which case the similarity of these sporangium-like

<sup>1</sup> Zeiller (96<sup>1</sup>) p. 369.

<sup>3</sup> Hooker & Greville (31) pl. xev.

<sup>4</sup> Oliver & Scott (04) p. 239.

<sup>2</sup> Seward (97<sup>1</sup>) p. 319.

<sup>5</sup> Kidston (04).

bodies to the microsporangia of the Cycads, which has been emphasized here, would have a special significance. It is hoped that, by calling attention to the importance of a further study of the scale-fronds of *Glossopteris*, a stimulus will be given to the collection of additional specimens, which may throw further light on these problems.

In conclusion, I wish to express my great obligations to Dr. D. H. Scott, F.R.S., who has, throughout this work, most kindly given me the benefit of his opinion and advice on the more difficult problems which have arisen. I would also express my thanks to Dr. A. Smith Woodward, F.R.S., Keeper of the Geological Department of the British Museum (Natural History), for obtaining for me the loan of the specimens in that Museum, and for the interest which he has taken in the progress of the work.

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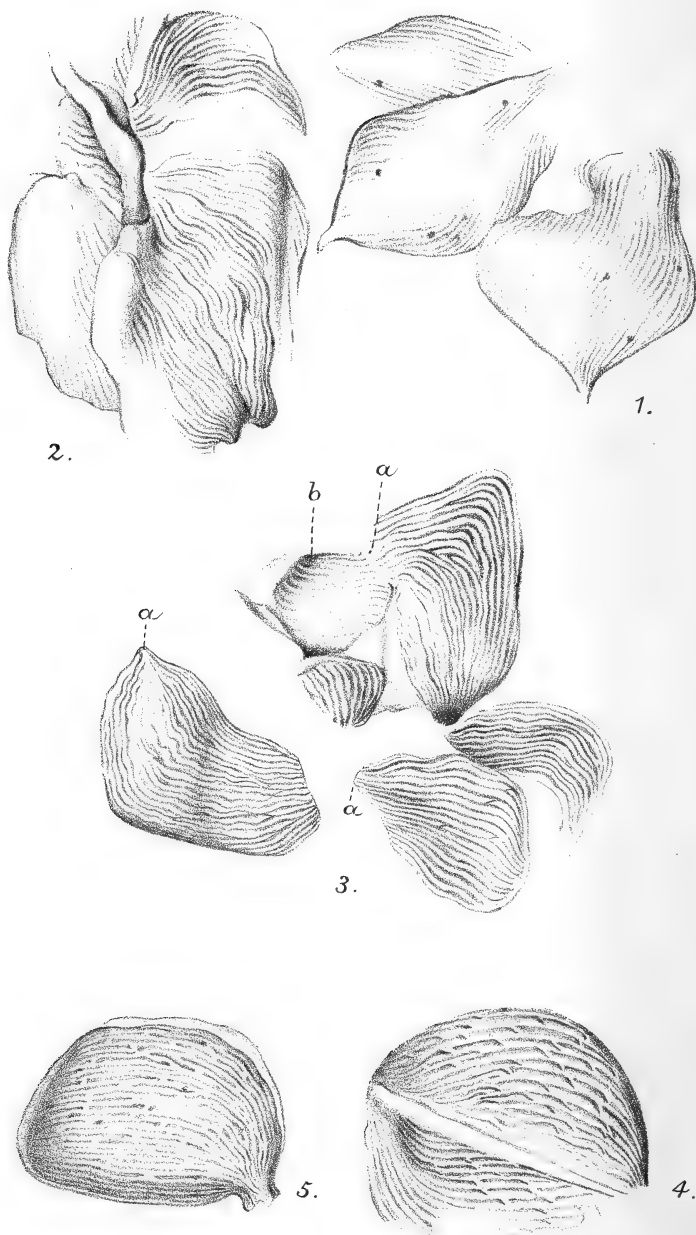
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## EXPLANATION OF PLATES XXX &amp; XXXI.

[The drawings are by Miss G. M. Woodward. All the specimens figured, except Pl. XXXI, fig. 5, are in the Geological Department of the British Museum (Natural History).]

## PLATE XXX.

- Fig. 1. Sporangium-like organs of *Glossopteris Browniana*, Brongn. Detached sac-like bodies: the larger specimen shows what was probably the apex (*a*) of the organ, at which point dehiscence appears to have begun. In the smaller, the dehiscence is well marked, but the specimen is more fragmentary.  $\times 35$ . Reg. No. V. 7202.
2. A nearly-perfect specimen of one of the detached sporangium-like organs, showing the apex (*a*), at which the sac appears to have opened, and the contents to be exposed. A small portion of the neck (*b*) is also seen. The cell-walls of the outer limiting-layer of the sac are very conspicuous.  $\times 30$ . Reg. No. V. 7211.
3. A group of four detached bodies, arranged in a sorus-like manner. In specimen *x*, the neck-like extremity, by which the sporangium was probably attached, is indicated. In specimen *y* the sac appears to have dehisced, and the inner concave surface is seen, the cell-walls of which are much less conspicuous than those of the outer.  $\times 30$ . Reg. No. V. 7202.
4. A fragment of a scale-frond of *Glossopteris Browniana*, showing the inner, strongly-concave surface. The nervation is preserved, although somewhat faintly. At the lower portion of the figure (*d*), a confused mass of the sporangium-like bodies occurs, resting on the scale-leaf. Higher up may be seen a row of oval scars or prints (*a*, *b*, *c*), possibly the points of attachment of sori. The scars, *b* and *c*, are well defined, and here fragments of the sac-like bodies appear to be still in continuity. At *e*, some of these sac-like bodies are better preserved, but it cannot be determined whether they are attached to the scale-frond.  $\times 15$ . Reg. No. V. 7202.

## PLATE XXXI.

[Figs. 1-4: Sporangium-like organs of *Glossopteris*. Fig. 5: A micro-sporangium of *Stangeria paradoxa*.]

- Fig. 1. Three of the sac-like organs, which appear to have dehisced: the inner, concave surface being seen. The cell-walls of the inner limiting-layer are much less conspicuous than those of the outer.  $\times 30$ . Reg. No. 39,149.

Fig. 2. A group of several detached bodies arranged in a sorus-like manner. Some of them appear to have dehisced; those on the right hand exhibit the outer surface, while those on the left exhibit the inner, of which the cell-walls are much less conspicuous.  $\times 30$ . Reg. No. 39,149.

3. A typical group of detached sporangium-like organs, showing the shape of the sac-like bodies and the conspicuous cell-walls of the outer layer. The neck-like extremity, probably the point of attachment, is seen at *a*. The inner surface of a fragment of a sac which has dehisced is shown at *b*.  $\times 30$ . Reg. No. V. 7202.
4. Fragments of the sac-like organs of *Glossopteris*, showing the shape of the cells of the outer limiting-layer of the sac.  $\times 30$ . V. 7211.
5. A microsporangium of a recent Cycad, *Stangeria paradoxa*, Th. Moore, for comparison with the sporangium-like organs of *Glossopteris*.  $\times 30$ .

#### DISCUSSION.

Dr. D. H. SCOTT said that he thought that the Author had a good case: he would not go beyond that. The sac-like form of the organs appeared to dispose of the suspicion that they might be merely concave ramenta. The fact that no spores had been found, though unfortunate, was no argument against the sporangial nature of the bodies; even in well-preserved petrifications, certain types of sporangia were almost always found empty. Exannulate sporangia were so common, that the absence of an annulus had no weight whatever as a negative argument. He agreed with the Author as to the worthlessness of the evidence formerly adduced for the presence of sori on the ordinary fronds. He would like to ask the Author, about on what proportion of the specimens of scale-fronds the supposed sporangia had been found. He thought that the systematic position of the genus was still quite an open question; there was nothing as yet, even assuming the correctness of the conclusions suggested by the Author, either to prove or disprove that *Glossopteris* was a true Fern. Analogies for the supposed position of the sporangia on the scale-fronds might be found both among Ferns and Cycads, although in either case the analogy was somewhat remote.

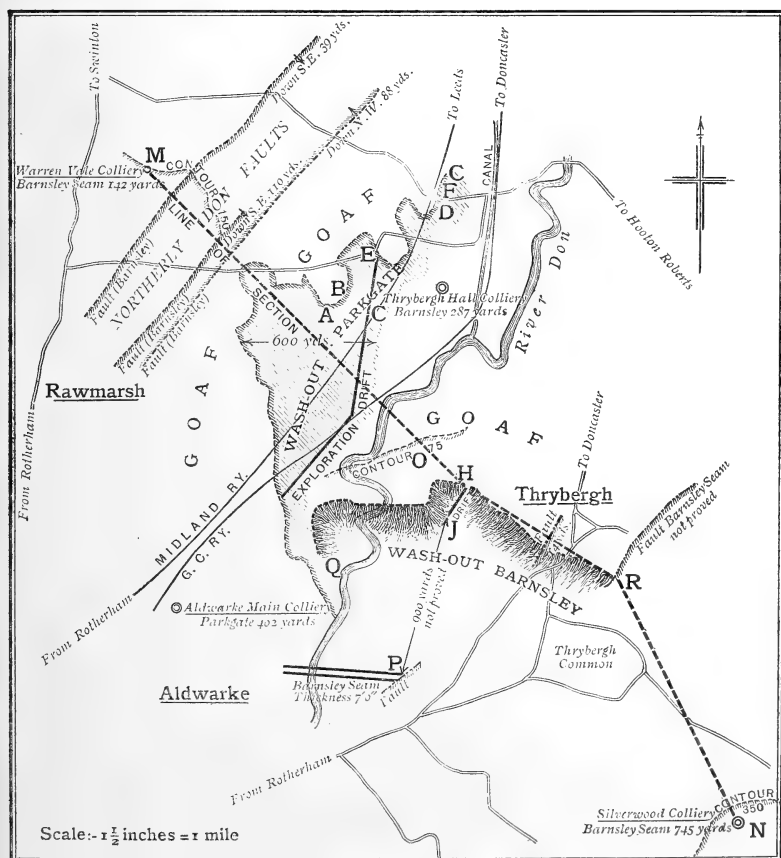
THE AUTHOR thanked the Fellows for their kind reception of a paper, which, he was afraid, was more of botanical than of geological interest. Replying to a question raised by the previous speaker, the Author pointed out that very few specimens of the scale-fronds of *Glossopteris Browniana* existed in this country, but that, with few exceptions, those which he had examined were associated with detached groups of the sporangium-like organs. The Author had pointed out that the characters of the sac-like bodies differed from those of the sporangia of any family of the recent Ferns, but he had not intended to imply that *Glossopteris* must necessarily be removed from the class Filicales. He was quite prepared to regard the question of the true affinities of this genus as an open one at the present time.

14. *On the WASH-OUTS in the MIDDLE COAL-MEASURES of SOUTH YORKSHIRE.* By FRANCIS EDWARD MIDDLETON, F.G.S. (Read February 22nd, 1905.)

DURING the past 20 years the South Yorkshire Coalfield has been developed and explored in the neighbourhood of Aldwarke and Thrybergh, lying 4 miles north-west of Rotherham, where the principal seams have been extensively worked, namely:—

The Barnsley Seam .....	7½ feet thick.
The Swallow-Wood Seam .....	5 feet thick.
The Parkgate Seam .....	4½ feet thick.

Fig. 1.



As the workings have extended, large areas have been proved to exist, where the coal has been removed by wash-outs which have

Fig. 2.—Section MN. (See plan, fig. 1, p. 339.)

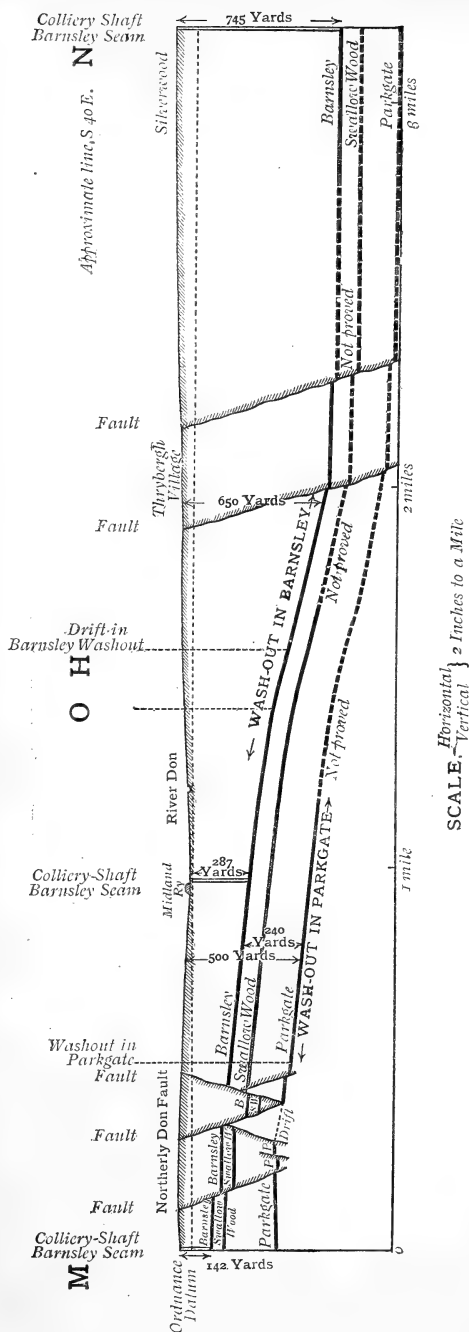
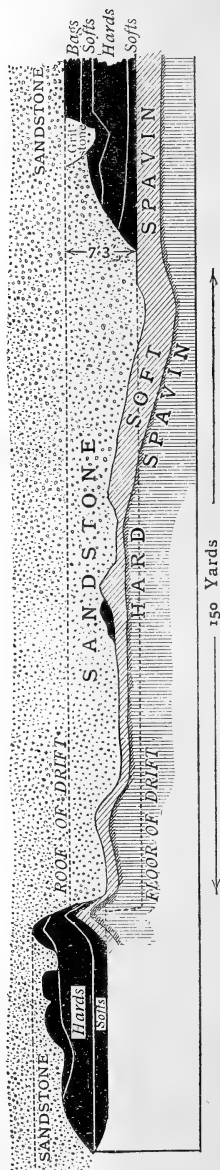


Fig. 3.—Section JH. (See plan, fig. 1, p. 339.)



Horizontal Scale — 1 inch = 132 Feet  
Vertical Scale — 1 inch = 20 Feet

occurred at various horizons in the Middle and Lower Coal-Measures; and it is only by defining these accurately, by survey upon plans, that any intelligent idea can be formed of their origin or probable extension.

On the accompanying plan (fig. 1, p. 339), the position is shown of a wash-out in the Barnsley Seam, which has been proved to exist from Q to R—1700 yards in an east-and-west direction, and by a drift—H to J in a transverse direction.

In the Parkgate Seam, which lies 240 yards below the Barnsley, another wash-out has been proved, covering the area, as shown by the diagonal shading, for a distance of 2600 yards in length in a north-and-south direction, and found to extend 600 yards in width.

The thickness of the strata overlying the wash-out in the Barnsley Seam is 650 yards, and in the Parkgate Seam 500 yards. The position is more clearly defined on reference to fig. 2, section M to N (p. 340).

The Swallow-Wood Seam, lying 60 yards below the Barnsley, has been partly worked under the same area, but no signs of a wash-out have been found, and the section is normal and uniform.

In order to define more clearly the dip of the measures, and the position of the seams referred to, a section (fig. 2) has been drawn, the line of which is shown in fig. 1. The direction is S. 40 E., and about the true dip of the seams, extending over 3 miles.

Starting at the point M, where the Barnsley Seam is 142 yards deep, and, after crossing the well-known Northerly Don Fault (referred to in the Geological Survey Memoir on the Yorkshire Coal-field, 1878, pp. 499-500), the inclination of the strata is half an inch to the yard, and gradually increases until it reaches the point O, where it is 16 inches to the yard; then it decreases in a like manner towards the Silverwood Colliery at N, where the Coal-Measures are practically level, and the Barnsley Seam lies 745 yards deep.

#### THE BARNSELEY SEAM.

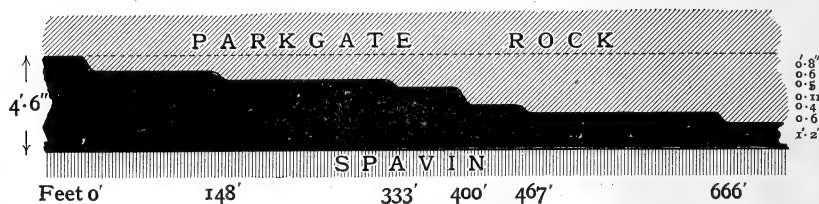
Fig. 3, section J H (p. 340), shows a drift driven from the plane of the seam, and proves the disappearance for 150 yards of the coal, the original site of which has been filled up by sandstone of a similar nature to the roof overlying the coal. The coal presumably has all been stripped and denuded throughout this distance, and it has not been proved to exist in a normal condition nearer than 900 yards from the face of the drift marked P on the plan (fig. 1, p. 339).

The Coal-Measures are much disturbed and contorted, and in some places appear to have been thrust up above their original position; therefore it is evident that the wash-out took place, or was formed, at a time antecedent to the disturbance.

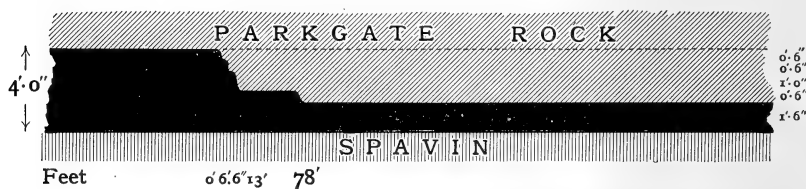
The drift has been driven forward 230 yards from H; at the beginning the sandstone overlies the coal, and a similar bed was found at the end of drift J, at which point the drift was discontinued.

Fig. 4.

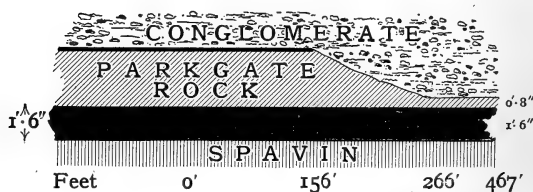
SECTION A.



SECTION B.



SECTION C.



SECTION D.

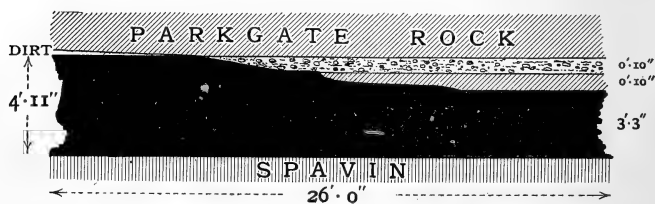
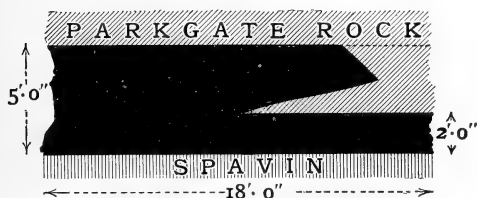


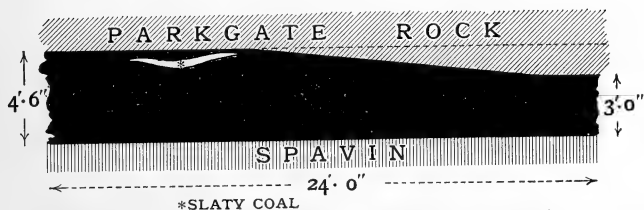


Fig. 4 (continued).

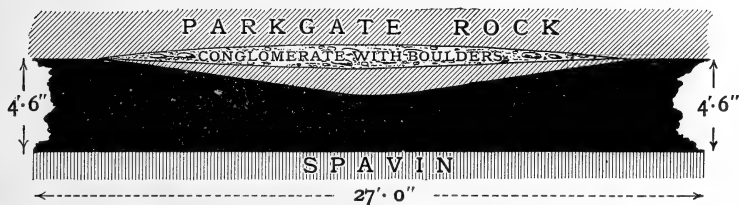
SECTION E



SECTION F.



SECTION G.



NORMAL SECTION OF PARKGATE SEAM



## THE PARKGATE SEAM.

In fig. 4 (pp. 342-43), the sections A, B, C, D, E, F, & G are also taken from actual measurements, and their positions are defined on the plan (fig. 1, p. 339).

The average thickness of this seam is 4 feet 6 inches, as described in fig. 4. In most cases the Parkgate Rock overlies the coal: from these sections it will be clearly seen where the seam has been removed.

The material that has replaced the coal differs very slightly from the ordinary rock overlying the coal, but sometimes a bind or argillaceous shale (which decomposes into a clayey soil on exposure to the atmosphere) interposes between the rock-roof and the coal for a few yards, at other times for 200 to 300 yards. In some cases, this bind thickens to 4 or 5 yards.

In sections C, D, and G (fig. 4), a conglomerate-rock interposes, with pebbles ranging in size from about half an inch in diameter to oval-shaped boulders 18 inches long.

In conclusion, my opinion is that the wash-outs occupy the sites of winding streams or rivers; these, during the formation of the coal-seams, meandered through the alluvial tracts in which the seams were being laid down, and washed the vegetable matter away, replacing it with sediment of a different character which the streams held in suspension.

## DISCUSSION.

Mr. Fox STRANGWAYS said that these wash-outs were very common in the Leicestershire and South Derbyshire Coalfield, but there was one curious case on the western side of the Coalfield to which he ventured to draw the attention of the Society. This occurred in the Eureka seam of coal in the Netherseal Colliery, and was pointed out to the speaker by Mr. G. J. Binns. In this case the wash-out, instead of being one broad hollow, consisted of numerous confluent streams, which united together into a main channel like the head-waters of a drainage-system. It would, therefore, appear that some wash-outs were caused by stream-denudation after the formation of the coal-seam.

Prof. P. F. KENDALL pointed out the unusual interest attaching to the superposition of two wash-outs, in seams separated by a considerable interval. At Silverwood the depth to the Barnsley Bed was 745 yards and at Cadeby 750 yards, and this was the typical area of development of the Red Rock of Rotherham, interpreted by the late Prof. Green as a wash-out. There might be some significance in the proximity of the pre-Permian Don-Valley Faults, and it was just possible that wash-outs were explicable on the theory of contemporaneous movement.

15. *An EXPERIMENT in MOUNTAIN-BUILDING: PART II.* By the Right Hon. the Lord AVEBURY, P.C., F.R.S., P.S.A., For. Sec. R.A., F.G.S. (Read March 22nd, 1905.)

IN 1903 the Society did me the honour of publishing a short paper on this subject.<sup>1</sup> I may, perhaps, just repeat that Sir James Hall many years ago, and others since, have illustrated the formation of folded mountains by placing layers of cloth under a weight, and then compressing two of the sides so that the cloth was thrown into folds. Since then, other and more complete, experiments of the same kind have been made by Favre, Cadell, Daubrée, Willis, Ruskin, and others.

In these investigations the compression was from two sides only. If, however, folded mountains are caused by contraction due to the cooling of the earth, the compression must take place from all sides.

With the view of illustrating this, I requested the Cambridge Philosophical Instrument Company to make for me an apparatus consisting of four square beams of wood, resting upon a floor, which by means of screws could be moved nearer to, or farther from, each other. The beams left between them a space 2 feet across and 9 inches in depth.

In this square central space I placed layers of cloth, baize, oil-cloth, cement, etc., separated by layers of sand. The machine was then set in motion, and compressed so that the central space was reduced from 24 inches square to 22.

Since last year I have made other experiments, changing the arrangement in various ways. The results differ in details in almost every case, the initial movements being probably determined by slight differences in the texture of the substances employed.

As a typical case I may cite fig. 1 (p. 348), representing a piece of compressed baize. It will be observed that there are two main folds, which cross at a right angle; that the elevation is greatest where the two folds meet; and that, while one fold is continuous, the other and lower one is shifted somewhat to one side, for a reason to which I will presently refer. Fig. 2 (p. 348) represents another specimen also showing the cross-ridges. Fig. 3 (p. 349) exhibits similar features, but the hills and valleys are more complex, and therefore more like those in Nature. Secondary cross-folding is well shown, and there is the same lateral shifting of one arm of the cross. The elevation is shown by fig. 4 (p. 349) which gives a lateral view.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lix, pp. 348-55 & figs.

Figs. 5-8 (pp. 350-51) represent a series taken in January. The machine was packed as follows:—

- 4 inches of sand.
- Thin oilcloth.
- 1½ inches of sand.
- Cloth (medium thickness).
- 1½ inches of sand.
- Thin oilcloth.
- 1½ inches of sand.
- Cloth, as before.
- 2 inches of sand.

The screws were then turned 3 inches.

Fig. 5 (p. 350) represents the upper layer of cloth, thrown into sharp ridges. Fig. 6 (p. 350) represents the layer of oilcloth. The general plan is the same, but the ridges are fewer. Fig. 7 (p. 351) represents the second, lower, layer of cloth. The ridges are numerous, and have a well-marked tendency to arrange themselves in squares, as, for instance, in Kjerulf's map,<sup>1</sup> but are less pronounced than they would have been if they had not had the oilcloth over them. Fig. 8 (p. 351) represents the lower layer of oilcloth: the ridges are less numerous than in the softer and more flexible cloth.

For contrast, I give figs. 9-13 (pp. 352-54), which represent another series taken at the beginning of this year. The machine was packed as follows:—

- 3 inches of sand.
- Cloth as before.
- 1½ inches of sand.
- Linoleum.
- 1½ inches of sand.
- Cloth.
- 1½ inches of sand.
- Linoleum.
- 2 inches of sand.

The screws were then turned 3 inches, reducing the square from 24 inches to 22.

Fig. 9 (p. 352) represents the upper layer of cloth, which was similar to that used in the preceding series. It will be seen, however, that the folding is altogether different, owing to the influence of the underlying linoleum. This is shown in fig. 10 (p. 352). The bold sweeps are striking, and the curved valley will recall many which occur in Nature. Fig. 11 (p. 353) represents the lower cloth, which, as will be seen, shows more numerous minor folds. Fig. 12 (p. 353) represents the lower layer of linoleum. The general arrangement is the same, but the folds are sharper; in fact, the linoleum was broken along the principal ridges. Fig. 13 (p. 354) gives a lateral view.

On the other hand, the case is very different if we introduce a stiff layer of some substance such as cement. This cannot throw itself into folds, but breaks and tilts itself up, assuming the

<sup>1</sup> 'Geologie des südlichen & mittleren Norwegen' 1880, p. 330, figs. 279 & 280.

so-called 'writing-desk' form of Sir Leslie Stephen, so familiar to us in the Alps, and finally breaks into fragments. In some experiments these were irregular, much broken up, and in that case forced irregularly into the sandy layers in a manner that would be very puzzling to geologists, and may throw light on some difficult problems.

In others, they broke across in two rectangular fractures, as in fig. 14 (p. 354). In such a case one half (fig. 14, *a, b*) was forced over the other, *c, d*. There was also an overthrust of *a* over *b*, and of *c* over *d*. Fig. 15 (p. 354) gives a lateral view, from *c* to *d*, showing the overthrust of *c* over *d*.

The result of these fractures and overthrusts is that, instead of two cross-lines, there is a three-legged ridge consisting of a single main elevation, with a break at, or near, the centre, from one side of which a main-cross line proceeds nearly at right angles. The corresponding cross-line (fig. 1, p. 348) on the other side is lower, and is shifted to some distance, according to the amount of overthrust.

The result is, that along the lines of overthrust a boring would pass twice through the originally-single calcareous stratum, and near the central nucleus of fracture even four times.

This accounts for the shifting of the lower ridge in figs. 1 & 2 (p. 348). One is reminded of the great arch of the Alps lying at right angles to the ridge of Italy, and that of the Himalayas with India, the plain of Lombardy corresponding to that of Bengal.

In other cases, the edges of the primary fractures broke off more or less regularly. The detached pieces were then pushed up, assuming gradually a very steep angle (fig. 16, p. 355), or even becoming vertical. The main plates of plaster having now room, were able to approach one another as in fig. 17 (p. 355), without any need for more fractures or folding. Such a case is illustrated in the accompanying diagrams (figs. 16 & 17, p. 355).

It will be observed also that a layer of pliable material above the plaster would be thrown into one or a few extensive folds; while a similar layer below is prevented from doing so, the under side being comparatively flat. It accommodates itself, therefore, to the circumstances by assuming a greater number of smaller folds.

Speaking generally, it may be said, firstly, that the thicker and stiffer the materials which alternated with the sand, the bolder and fewer are the folds; secondly, that the folds are more numerous and more accentuated in the lower layers; and thirdly, that the folds tend to be at right angles one to the other.

#### DISCUSSION.

The PRESIDENT observed that there were some who believed that laboratory-experiments threw little light upon Nature's work, but we could approximate more and more closely to the conditions which obtained in Nature, though we could never actually imitate

Fig. 1. (*See pp. 345, 347.*)



Fig. 2. (*See p. 345.*)

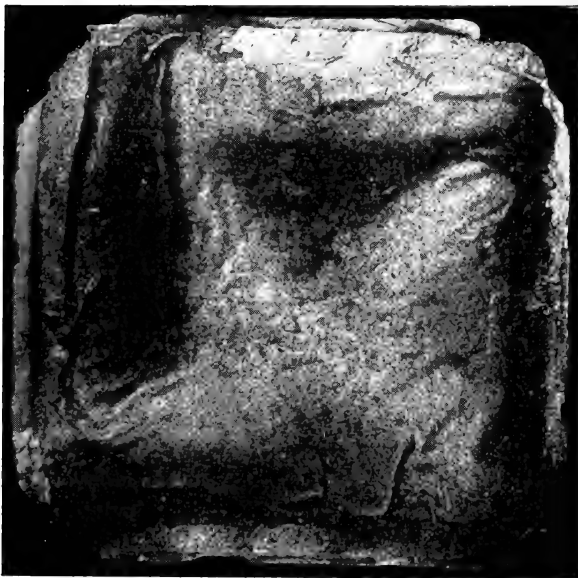


Fig. 3. (*See p. 345.*)

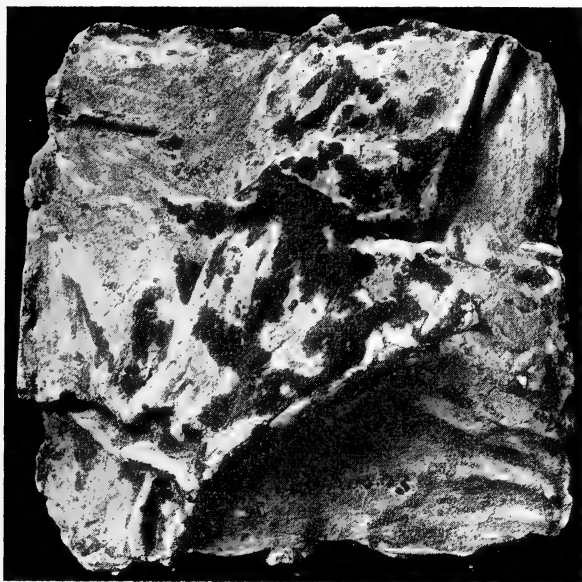


Fig. 4.—*Lateral view of the above.*

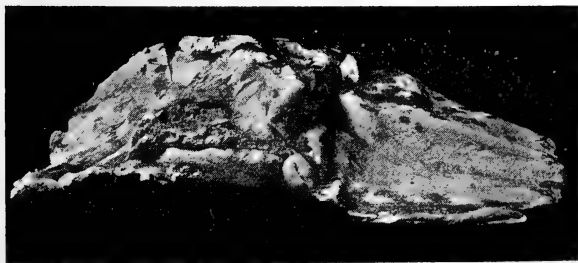


Fig. 5. (*See p. 346.*)



Fig. 6. (*See p. 346.*)





Fig. 7. (*See p. 346.*)



Fig. 8. (*See p. 346.*)



Fig. 9. (*See p. 346.*)

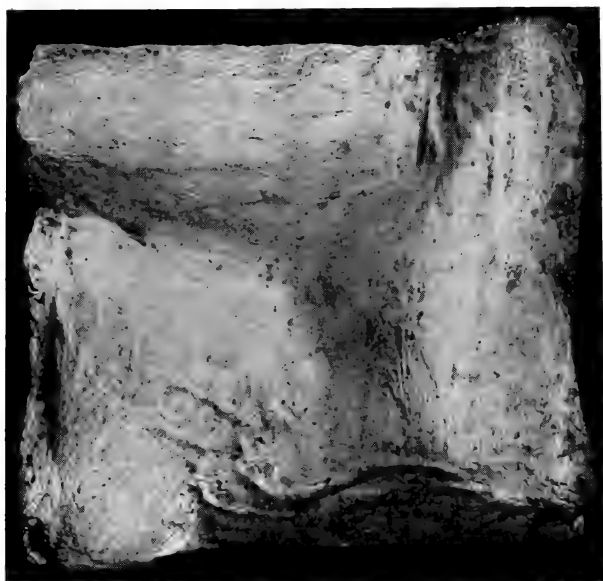


Fig. 10. (*See p. 346.*)

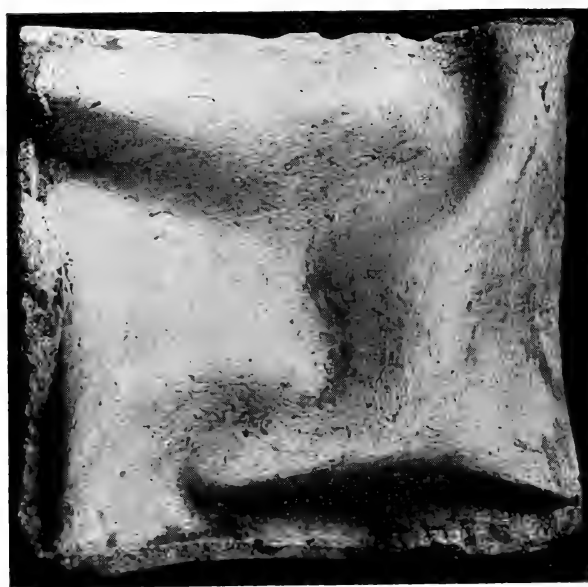


Fig. 11. (*See p. 346.*)



Fig. 12. (*See p. 346.*)



Fig. 13.—*Lateral view of the cast illustrated in fig. 12.*

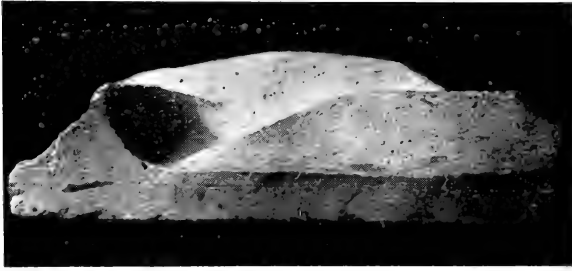
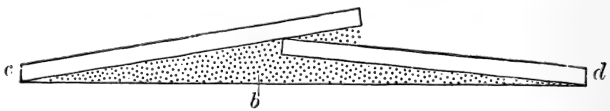


Fig. 14. (*See p. 347.*)

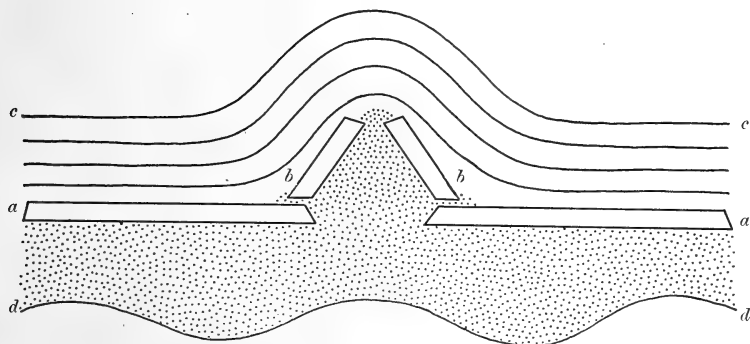


Fig. 15.—*Lateral view of the above.*



*c, d = plaster ; b = sand.*

Fig. 16. (See p. 347.)



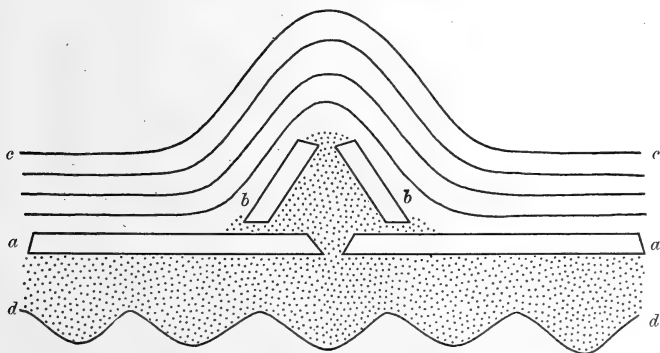
*aa* = Two halves of a layer of plaster fractured in the middle, and again a second time.

*bb* = Pieces broken off and forced up.

*cc* = Layer of flexible material above the plaster.

*dd* = Layer of flexible material below the plaster.

Fig. 17.—Showing the same materials as in fig. 16, but more compressed.



them: for instance, it was doubtful whether we could ever get sufficient pressure to imitate exactly that flow of solids of which there was evidence among the rocks.

The initial experiments of Favre were simple, but others, as Cadell and Willis, had made more elaborate experiments, and the Author had introduced further complications.

The paper which had just been read was a continuation of one previously presented to the Society by the Author, and the President hoped that Lord Avebury would continue his interesting experiments and bring further results before the Society.

Dr. BLANFORD said he thought that the Society were greatly indebted to the Author for a most interesting series of experiments. He was particularly impressed by the crossed faults produced in the layer of plaster, as this probably showed the way in which lateral pressure might act on a rigid bed intercalated among more flexible strata. The form of the surfaces produced naturally differed from that of the usual superficial features of the land, because of the absence of the erosive action of denudation.

Prof. GARWOOD asked the Author whether sections cut through the models showed the formation of cavities such as might induce the intrusion of igneous rocks in Nature, and such as seemed to have taken place in mountain-ranges like the Eastern Himalaya.

Mr. LAMPLUGH remarked on the close resemblance of the plications on the surface of the models which contained linoleum, to the corrugations sometimes shown by compressed gritty flags in the Isle of Man and at Bray Head in Ireland.

Mr. STRAHAN thought that the imitation of forms of surface produced by denudation, by the surfaces of the models as produced by folding, was apt to mislead, and suggested that a truer comparison with Nature might be obtained by planing off the surfaces of the casts to a level, and developing valleys and escarpments by erosion. The model showing two intersecting overthrusts was especially instructive. Though contemporaneous with it, one overthrust clearly broke through, and displaced the other. Moreover, the one that was broken through was overthrust from opposite directions in its two halves, in this respect resembling belts of overthrusting and compression in Nature, which, unlike normal faults, were apt to change their throw.

It would be interesting to see a reproduction of a structure that he had recently observed in Pembrokeshire. There a gentle anticline was accompanied by a multitude of small overthrusts. Without exception, the overthrusting was from the south on the south side, and from the north on the north side of the anticline. Even in the few yards of nearly-level strata in the crest, four or five little overthrusts strictly followed this rule. He joined previous speakers in hoping that these interesting experiments would be continued.

Mr. WHITAKER enquired what was the amount of pressure exerted on the top during the whole of the experiments.

The AUTHOR thanked the President, and the other Fellows of the Society who had spoken, for their kind remarks. It was said that

the casts 'too closely' resembled Nature. He observed that when the surface on which rain, etc. had to act was so irregular as in the casts exhibited, the result would mainly be to deepen the original valleys. There would be, as the models showed, at first some lakes, which would be drained by more or less deep and narrow gorges.

In reply to Mr. Whitaker, he said that there was a thickness of 3 or 4 inches of sand overlying the top layer of cloth. The actual materials used showed such hollows as those suggested by Prof. Garwood, and into these sand had been forced up, but the hollows could not, of course, be reproduced in the casts.

16. *On the ORDER OF SUCCESSION of the MANX SLATES in their NORTHERN HALF, and its BEARING on the ORIGIN of the SCHISTOSE BRECCIA ASSOCIATED THEREWITH.* By the Rev. JOHN FREDERICK BLAKE, M.A., F.G.S. (Read February 22nd, 1905.)

### I. INTRODUCTION.

AMONG the slates of the Isle of Man some strata have been found which represent, in the opinion of Mr. G. W. Lamplugh, so distinct a type of phenomenon that he assigned thereto a special name—that of a ‘crush-conglomerate.’ In the earlier announcement of this result in 1895,<sup>1</sup> he defined the rock as ‘made up of scattered fragments set in a slaty matrix,’ and considered it ‘due to the breaking-up under pressure of alternations of flaggy slate and thin grit-bands’ (*op. cit.* p. 565). So far as this general statement goes, we shall find it included in the description of many fragmental rocks; but when we seek further information, and enquire concerning the fragments whether they be angular or round, scattered or crowded, uniform or various, composed of neighbouring rocks or of remote ones, and of the pressure, whether it be shearing or otherwise, metamorphosing or not—then our troubles begin.

The paper in the Quarterly Journal was only a preliminary account of what had been observed, and a full statement was promised when the Geological Survey-Memoir on the island should be published, which took place in 1903. I had early, however, taken an interest in the question, owing to the inclusion by Sir Archibald Geikie of some rocks in Anglesey in the same category.<sup>2</sup> But I had not to wait so long as 1903, for, with the greatest kindness, Mr. Lamplugh lent me some advance-proofs of the principal passages involved, and thereby enabled me to spend portions of four successive summers in the island, amounting in all to about seven weeks of consecutive work, in examining all parts likely to throw light upon the subject, with the aid of the 6-inch maps as shown in the office of the Geological Survey.

From a study of the literature thus made available, it soon becomes apparent that a primary stage of the investigation consists in a determination of the lie and position, and thereby of the order of succession, of the Manx Slates in which these strata lie.

### II. THE ORDER OF SUCCESSION OF THE MANX SLATES.

The determination of the order of succession of the various members of the Manx-Slate Series is a matter, on the whole, of considerable difficulty: owing, in the first place, to the relative paucity of exposures over wide areas, the solid rocks being much

<sup>1</sup> Quart. Journ. Geol. Soc. vol. li, p. 564.

<sup>2</sup> Geol. Mag. 1896, p. 481.



concealed by the abundance of their own débris, which may be more or less mixed and removed from their original site; and, in the second place, to the similarity in many of their aspects of portions of the different members themselves, when seen otherwise than in mass. And when, to these difficulties, we add the easy confusion so often introduced by cleavage of a complicated character, and the indubitable contortion to which parts are subject, we have all the elements united which might lead us to despair of ever solving the problem.

There is no cause for wonder, then, that we read such expressions as the following in Mr. Lamplugh's recent Survey-memoir:—

'It cannot be pretended that more has been done than to trace out the broader elements of their stratigraphy. . . . There are broad tracts . . . in which the different varieties are so closely intermingled as to be practically inseparable. . . . Their relative order has not been established with any certainty, and still remains a matter of inference. . . . The chief impediment to more detailed stratigraphical work has been the failure to find bands smaller than the[se] main divisions, with characters distinct enough to be constantly recognizable. . . . The apparent dips are altogether misleading as to the superposition and stratigraphical relations of the strata.' (*Op. cit.* pp. 28, 29, 30.)

Phrases such as these, together with the adoption of no colour for a wide area left as 'unseparated,' show that the order of succession has not been determined; and we are left without the knowledge whether the fragments contained in some of the rocks called conglomerates are derived as usual from the strata below them, or, by exception, from the strata above them!

In determining the order of succession in a series of unfossiliferous strata, we are deprived of the direct guidance of recognizable fossils, and have consequently to depend on stratigraphical considerations which have been less studied but which, from experience, render it more probable that fine-grained deposits follow coarser-grained, except for 'episodes'; and show that the more metamorphosed rocks are usually *cæteris paribus* the older. Details of structure, such as cleavages of various kinds, do not affect the order of succession, and may therefore be neglected, for a rock when uncleaved will have the same position relatively to its neighbours as when cleaved.<sup>1</sup> These and many similar axioms render it unnecessary to determine the nature of every rock if, by the selection of suitable spots, we can determine the order of succession in parts, and unite the observations into a whole.

### (1) The Barrule Slates.

We commence with the rocks which form the central axis of the island, and rise to the greatest height. They are called the Barrule Slates by Mr. Lamplugh, and are of great visible thickness. They are black and characterless where most fully developed, the only apparent divisional planes being due to cleavage.<sup>2</sup>

<sup>1</sup> Further details with regard to 'nappes de charriage' are required; see Marcel Bertrand, *Bull. Soc. Géol. France*, ser. 3, vol. xxvi (1898) p. 632.

<sup>2</sup> By this term it is intended to include all the smaller changes commonly assigned to 'earth-movement.'

We note that 'where its outcrop descends to below 900 feet in crossing the deep intervening glen between Snaefell and Beinn-y-Phott,'<sup>1</sup> it is contracted to a less breadth than that which it occupies at a greater height. On descending the slope into this glen from the east, near the inn where the tram-line crosses the road at a height of 1341 feet, we meet with numerous exposures of 'striped slates with gritty alternations,'<sup>2</sup> which at the base cross the stream with a steady dip north-westerly in direction, and are followed in the same direction by the (practically) dipless Barrule Slate till the lead-mine is reached, near which the section ceases. This section gives the first indication that, if the beds be not overturned, of which there is not the slightest sign, we see here the lower, eastern, border of the Barrule Slates, and that they are followed below by 'striped slates.'

### (2) The Snaefell Laminated Slates.

This subdivision of the strata is included in the Geological Survey-Memoir among the 'Strata of the Unseparated Tracts' (p. 54), apparently on account of their similarity to some portions of slates found at other horizons, a point which does not here concern us; but Mr. Lamplugh more particularly speaks of them as 'altered slate of Snaefell,' as well as 'striped slates.' As 'altered' has reference to a later effect, and 'striped' is indefinite, it is proposed to speak of them here by their main character as 'laminated,' that is, divided into thin flat bands of different petrographical character.

This group is characteristically described by Mr. Lamplugh as a

'belt of banded slates with gritty intercalations, which form the passage-beds between the Barrule Slates on the west and the Agneash Grits on the east' (*op. cit.* p. 527);

while in a neighbouring mine, situated on or near a fault, the 'deeper northward workings appear to enter the Barrule Slates' (*op. cit.* p. 527). Small exposures of the same rock called 'striped and puckered slate' are seen all along that part of the mountain-road that has passed to the east side of Snaefell. This, therefore, is the next member in the downward succession. It is defined by an alternation, not merely of colour, but of substance also. By the reduction of the proportion of the gritty bands, it merges insensibly into Barrule Slate; by the reduction of the slaty partings, it becomes altogether a laminated grit, in which the dark, soft lines are very narrow and often approximate, and the rock passes into the true Agneash Grit.

### (3) The Agneash Grit.

The rock which underlies the Snaefell Laminated Slate is a fine-grained subcrystalline quartzite, or hardened grit, arranged in groups

<sup>1</sup> Mem. Geol. Surv. 'Geology of the Isle of Man' 1903, p. 51.

<sup>2</sup> *Ibid.* p. 139.

of fine laminæ. It is a very distinct rock, though it may become less so in places. It may be seen, however, in its true form on both sides of the upper part of Glen Laxey, that is, in the tram-line cuttings on the opposite side of the valley from Laggan Agneash, and on the same side as Laggan Agneash in various exposures (the beds always dipping at various angles in a westerly direction), and may be traced thence over the slopes above. No other grit is comparable to this, in its altered form and laminated structure; and it is essential to distinguish it by those constant characters from those other less-altered, but unlaminated grits to which the same name has been applied. It is the lowest stratum, according to my observations, anywhere exposed on the surface of the island, at least in the northern part, unless some crystalline quartzite, also without lamination, seen near Slieau Ouyr, represent something lower.

With this stratum ends on the surface the typical triad of the older Manx Slates, exhibiting a steady north-westerly dip, though at various angles, with which any indications of folding do not interfere on a large scale. The order of their succession is the same as that adopted by Mr. Lamplugh, but there is nothing among them at all resembling a schistose breccia. To see this and its relations to the other strata, we must pass to the north-western side of the axis. Here, along a stream running a little to the north of the road which leads from Snaefell to Sulby, and enters the glen by the waterfall at Tholt-e-will, we get in the upper reaches a 'reappearance of the striped slates, with gritty alternations like those seen higher up.' These are accounted for by Mr. Lamplugh as an upturn of the same strata, but there is no evidence of any change of dip; they continue the same dip as before, and are followed by the Barrule Slates as before; in other words, there is a repetition of the upper part of the typical series, which was left behind when the Snaefell range was uplifted along a strike-fault. We are, therefore, on an ascending series<sup>1</sup> as we descend the gorge of Tholt-e-will, and at the end we find a series of slates of an ordinary appearance, but on breaking them up we find them full of fragments. We are thus introduced to the Schistose Breccia.<sup>2</sup> It is associated with the Barrule Slate, of which it appears as forming a part; but we must seek for this more certain proof, for in this part of the island there are many places where rocks are marked as 'crush-conglomerate,' in which no sign of a fragment is seen, included, we must suppose, in the 'certain bands in which the bedding-planes are only partially disrupted' (*op. cit.* p. 65).

#### (4) The Schistose Breccia.

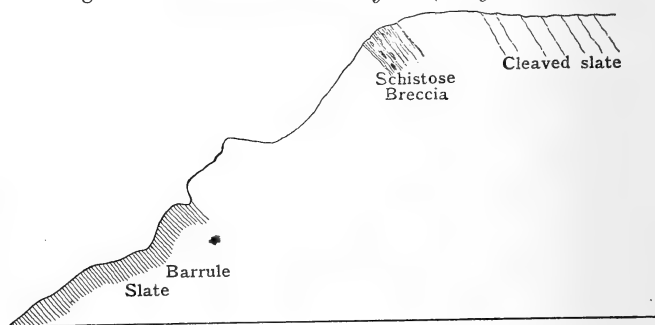
Glen Auldyn.—In the upper part of Glen Auldyn, a mass of Barrule Slate occupies the lower ground, and a stream descending

<sup>1</sup> See 1-inch Geol. Surv. Map, Sheet 100.

<sup>2</sup> See Mem. Geol. Surv. 'Geology of the Isle of Man' 1903, pp. 133-34.

from Skyhill joins the River Auldyn from the left. At the base of the crag forming the lower corner of this stream-valley, the slate is worked, and ascends the crag as far as it is accessible; the more level ground above this is crossed by a band of breccia, and this is followed farther up by highly-cleaved slate-rock (see fig. 1, below) of rather mongrel-character. This shows a definite ascending sequence, commencing with the Barrule Slate at the base, followed above by a schistose breccia with contained fragments, and ending with a mongrel slaty rock. From this spot, if we follow the probable outcrop of a regularly-bedded rock, we recognize the same Schistose Breccia crossing this branch-stream farther up, and on the hill-slope beyond

Fig. 1.—Section in Glen Auldyn. (Diagrammatic.)



the valley the same bed may be seen about halfway up the zigzag path. In all these cases the beds geologically above the Schistose Breccia are not well defined, as may be judged by the fact that all three have been included in the area referred to the Barrule Slate.

**Sulby Glen.**—The lower part of Sulby Glen stands nearly at right angles to the rest of the valley. Its north-eastern slope exposes a section, of which Mr. Lamplugh writes:—

‘Nowhere can the development of the structure [of the “crush-conglomerate”] and its relation to the accompanying strata be more satisfactorily studied than in these crags. . . . South-eastward it passes gradually into the dark Barrule Slate of Ballaneary, and north-westward into highly-contorted banded slaty and gritty flags’ (*op. cit.* p. 60);

with the Schistose Breccia occupying a large breadth in the centre. These crags are almost vertical at the summit, and crowded with obstacles, such as thick gorse and slippery bracken; yet we can see that the Breccia is not separated from the Barrule Slate by any mark of motion, but apparently passes into it gradually by the cessation of the fragments. It is different, however, with the contorted flags: these are thrown into the most magnificent folds, visible at a distance, or seen close at hand. The final direction of the upper folds in no way leads towards the breccias, but it is

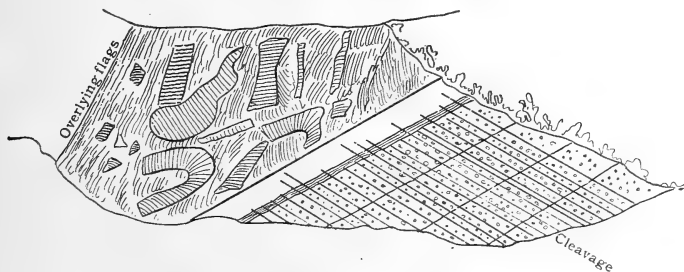
entirely separated from them by structures, seen in figs. 2 & 3 (below),<sup>1</sup> especially by the clearly-defined straight boundary seen in the latter figure.

On the evidence of the probable assumption, therefore, that the Barrule Slates form a definite horizon, which is recognizable from place to place, we establish the existence of an additional member, namely, the Schistose Breccia, occupying a position near, or at the summit of, the black slate. We thus have four consecutive members definitely ascertained, composing the Manx Slates in

Fig. 2.—Sketch of the folds in the overlying flags of Sulby Glen.



Fig. 3.—Junction of the Schistose Breccia with the overlying rocks at the Sulby-Glen Crags.



ascending order :—The Agneash Grit, the Snaefell Laminated Slate, the Barrule Slate, and the Schistose Breccia. There may be further members of the same series developed locally above the breccias; indeed there appear to be signs of the existence of such, but no adequate proof has as yet been worked out.

### III. THE GENERAL DISTRIBUTION OF THE MANX SLATES.

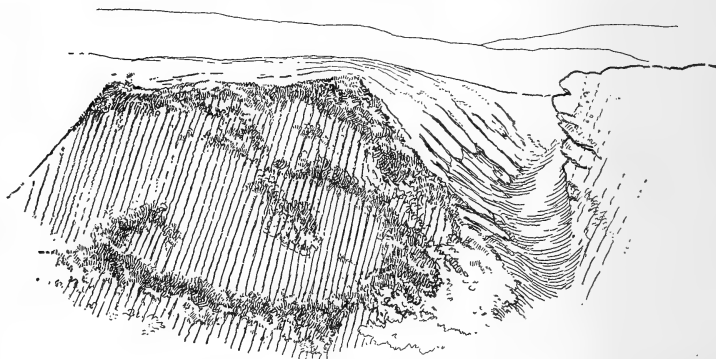
Considerable exposures of one or more members of the above-described series of Manx Slates may be recognized in various parts of the northern portion of the island (thanks to the Geological Survey-

<sup>1</sup> This is, apparently, the spot described in the Geological Survey-Memoir (p. 62) under the words 'Every stage in the breaking-up of these sandy slates and grits can be distinctly traced.'

Map and Memoir serving as guides), from Gob-y-Deigan on the west, to Maughold Head on the east.

Thus, the Agneash Grit, characterized in the field by being finely quartzitic, laminated (often closely), having a north-westerly dip of various degrees (often high), being succeeded by laminated slates, may be followed over the high ground above Agneash to Trinity Church, west of the Douglas road and south of Corran; and the Grit is seen in nearly-vertical bosses in the cliffs, and on the overlying surface at Maughold Head (see fig. 4, below). So far have I traced it towards the north. It doubtless continues to the south as mapped, and occurs again in the same relative position, with the slates of South Barrule and Cronk-ny-Arrey Lhaa. But, from all the areas to the north-west of the Barrule main axis, the above-described

Fig. 4.—*Agneash Grit, looking east, seen nearly vertical at Traie Earkan.*



characters are absent, and the rocks mapped as 'Agneash or other grits' must belong to the latter category, and have no connection with the Slate Series.

The overlying strata, that is, the Snaefell Laminated Slates, in like manner may be traced from the hills behind Agneash to Maughold Head, where they cap the head itself; and this headland, though not high as compared with the axial range, is higher than, and sharply protrudes from, the country immediately surrounding it, which is made up of rocks of a different character. We may see the Laminated Slates extruded at the sea-level to Port-e-Myllin, close up to the (mapped) commencement of the Barrule Slates, recognizing them by their dark colour, soft texture, and lamination combined, as well as by the curious cross-cleavage, which looks more like areas of contraction filled in with a lighter-coloured secretion, crossing irregularly from hard band to hard band, without moving them by anything like 'strain-slip.'

Since the Barrule Slates have been taken as the standard of comparison, there is no occasion to discuss their distribution, which will not differ from that indicated on the 1-inch Geological Survey-

map. It may be noted, however, that the successive ranges diminish towards the north in the northern part, and also to the west, the last two having little of the high dip of the first two: namely, that from Ballameanagh northward ranging from  $60^{\circ}$  to  $20^{\circ}$ , while the height at the end is not much above 500 feet; and that at Gob-y-Deigan being nearly horizontal, and on the sea-shore. This seems quite as easy of explanation by a series of subparallel faults radiating from the south of the island, as by infolds of the strata to which their regular north-westerly dip in a graduated amount does not correspond.

The distribution of the Schistose Breccia is dependent on the range of the Barrule Slate, with the western side of which it is always closely connected, and of which, except for the fragments it contains, it would appear to be a mere accident. Many, indeed, are the localities, especially in the north, which are included under 'crush-conglomerate' in the Geological Survey-map, in which there is no sign of a fragment. The presence of this sign, however, usually indicates that the rock is harder and 'shorter' in the grain. In the large range of Barrule Slate, which extends from the west side of Snaefell to Ramsey, the fragment-bearing breccia is found at its highest point in the island, 1100 feet, on the watershed of the Glen-Auldyn river. It is here very remarkable in its contents. I call it the Hill-Series. Thence we pass by the road south of Parkneakin, through the three localities on the west side of Glen Auldyn, on to Elfin Glen at the top of the quarry, and finally to the Albert-Tower Crags, the mountain-road, and the lower road to the Reservoir, all more or less in the direction of the strike. The dip, though variable, might take it to the low ground near the Ramsey road, and we find it north of Skyhill at the base of the road slanting up the hill.

The next series of exposures of the Schistose Breccia is connected with the great mass of Barrule Slate, which rises to 1257 feet in Slieaumonagh, but is lost sight of at either end. At one end is the magnificent river-section under the farm of Druidale, terminated by a fault crossing the river, and at the other, the equally, but differently, magnificent crag, before described. The rest of the section, from Tholt-e-will to Narradale and Cronk Sumark, is so interfered with by faults and other displacements, that it is of no use for teaching, but only for testing progress.

In the third range of the Barrule Slate, which occupies the hills to the north-east of Peel, we find the Schistose Breccia, where we expect now to find it, on the west, running parallel to its boundary, the intervening space being marked as Drift-covered; while, in the last locality where the slate occupies the shore, we find the breccia faulted down at the south-western boundary at Gob-y-Deigan caves, and mounting (*fide* Geological Survey-Memoir) at the other end upon the slate.

We thus find that the members of the series of the Manx Slates are repeated again and again in the order as they are first determined, according as they are raised above the surface of the earth.

## IV. THE POSITION OF THE LONAN AND NIARBYL FLAGS.

The rocks, the description of which has just been concluded, are surrounded on their east and west sides by another series of rocks, which have been called Lonan Flags on the east side, and Niarbyl Flags on the west side. Another portion is left as 'unseparated,' in other words is left unmapped. Nevertheless, Mr. Lamplugh says that it is more probable that the contorted grits and flags so largely developed at the lower levels of the island, pass as a highly-folded platform, beneath the argillaceous mass out of which most of the central hills are carved.

From this conclusion we must omit all those portions coloured with a common tint and marked *a* which includes these flags, and confine the statement to those which are coloured and marked *a*<sup>1</sup>. As these latter are not directly connected with the Schistose Breccia, their position is not immediately important; but that there are portions of the former group overlying the Schistose Breccia and its associates, is shown in many places, and it seems to me that they are part and parcel of the latter group.

The evidence regarding the latter group is as follows:—

(1) On the west side of the vertical Agneash Grit which forms Maughold Head there is comparatively low ground, in which at the sea-side there is massive material, colour-banded and obliquely cleaved, nearly horizontal; at Port Mooar there is the same kind, almost like Lias, becoming folded inland; higher up, by Ballajora, is a quarry, with characteristic flags of Lonan type (coloured as Agneash), dipping west at 40°; on the coast-region between Port-e-Myllin and Maughold Head, is a quarry showing straight folds and undulating surfaces, with uncleaved slates and grits; and nearer Maughold is a slaty stone-quarry, all of which resemble in no way the members before enumerated.

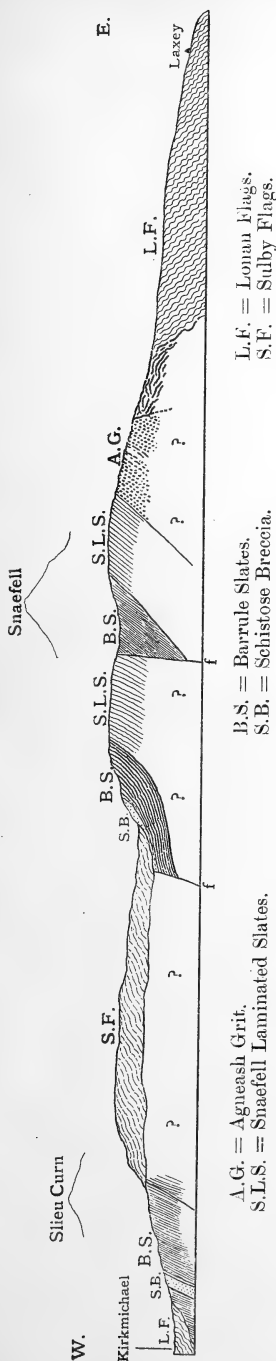
(2) At the great quarry near Ramsey, where the mountain-road turns up from the plain, some mongrel-rock is seen, dipping away from the Schistose Breccia behind it; and in Skyhill, the upper part shows well-bedded schists of Lonan type, with the Schistose Breccia passing beneath from side to side.

(3) At the Sulby-Glen great crag, we have the 'contorted grits and flags' before noticed overlying the great mass of Schistose Breccia; on the other side of the valley, they are seen by the road-side still highly contorted; and in the great quarry by Gob-y-Volley they are repeated in the same style where the contortions guide us, whence they continue bed after bed (no doubt contorted on a large scale) to form the high hills as far as Ballaugh and beyond: these might be called the Sulby Flags. Above the breccia-bed at Druidale we enter this series, which continues far away to the distant hills of Sartfell and Freeoghane.

(4) Above the railway, near Lady-Port, where it crosses the road, slaty grits and flags with no relation to Agneash Grit form long bands at a lower level, where the Schistose Breccia occurs still lower, between these grits and flags and the Barrule Slate.



Fig. 5.—*Interpretation-section through the Manx Slates.*



Other localities afford the following further evidences:—

(5) (Mem. p. 149) 'The remarkable difference in the number, character, and direction of the dykes in these slaty rocks [Nos. 2-4] as compared with those in the Niarbyl Flags [No. 5] seems at first sight to suggest that the Flags belong to a later system than the Slates' (Mem. Geol. Surv. pp. 37-38). Further, 'in the coast-section the slates are seen to be greatly crushed and confused in the vicinity of the junction, and they appear to pass beneath the flags.'

Among the presumptive reasons for belief in the later age of the Lonan Flags it may be mentioned that:—(1) No locality is recorded, nor can I discover one, where the Lonan Flags are seen underlying any member of the Slate Series. (2) Whereas every member of this latter series is more or less sub-crystalline and metamorphosed, every member of the Sulby-Flag Series is more or less earthy and largely unaltered. (3) Every appearance, real or imaginary, of an organic remain has been found only in the flaggy beds, and none anywhere in the Slate Series. (4) Occurrences of a flag are usually more accompanied by folding than any of the Slate Series, eleven out of twelve such illustrations being given in the Survey-Memoir, and this frequency argues for the lightness of the load that they had to bear. (5) The long series of flags in Laxey Valley, though commencing with contortions, but becoming more regular, extend over  $2\frac{1}{2}$  miles to their end, and even more if we include Clay Head, and yet show no sign of infolds of the supposed higher strata to which they are supposed to approach.

These are the chief reasons which lead to the conclusion that the

only history of the Manx Series of Slates which will satisfy the various conditions is as follows :—First, the triad of Agneash Grit, Snaefell, and Barrule Slates were laid down in regular order ; next, part of them, with possibly something additional, was broken up, and their fragments scattered over the still-forming mud, forming the Schistose Breccia ; after which they settled down along sub-radiate faulted blocks, each accompanied by the common breccia. These blocks united form a nucleus (as, in like manner, did Malvern, the Longmynd, and Charnwood), round (and partly over) which the long series of Sulby or Lonan Flags accumulated, without their stratification being governed by the strata buried beneath them ; but they partook of the later movements which modified both older and newer formations (see fig. 5, p. 367).

This account, however, involves the conclusions as to the character and origin of the Schistose Breccia, into which we are now prepared to enter.

#### V. THE CHARACTERS AND ORIGIN OF THE SCHISTOSE BRECCIA.

The rocks, to which the name of ‘crush-conglomerate’ was first applied by Mr. Lamplugh, have been subsequently recognized as having a supposed origin to which the name of ‘autoclastic’ had been previously applied by H. L. Smyth in 1891.<sup>1</sup> That author defines it thus : ‘Schists formed in place from massive rocks by crushing and squeezing, without intervening processes of disintegration or erosion, removal and deposition.’ Five years later, Prof. C. R. Van Hise, recognizing that a schist was only an advanced stage of fracture, added the words ‘frequently broken into fragments.’ Rocks, however, of this character had been known before the ‘nineties, such as the schists at the entrance of Bardon-Hill Quarry, near Charnwood Forest, but the rocks of the Isle of Man do not exhibit those characters.

All the rocks of either kind have abundant fragments, and most of the fragments lie in a schistose matrix. But Prof. C. R. Van Hise, in the 16th Annual Report of the United States Geological Survey (1894–95) pt. i (quoted above), discussing the ‘Origin of Autoclastic Rocks’ (quoted by Mr. Lamplugh), points out, under ‘Relations of Autoclastic Rocks to Basal Conglomerates’ (pp. 680–81), the criteria which distinguish between them, saying practically that the fragments of an autoclastic rock must be derived from the adjacent materials, whether they be below or above ; and the rock itself may be traced into an ordinary brecciated form. This is not a mere question of nomenclature, but of the origin of the rocks themselves. If two rocks are rubbed together, and fragments are produced, these fragments must be recognized as belonging to the rocks that have been rubbed ; that they belong to the same series is nothing—they must be adjacent before they can be separated in an autoclastic

<sup>1</sup> Amer. Journ. Sci. ser. 3, vol. xlii, p. 331.

manner; and, since normally only two rocks can be adjacent to one spot, three or more varieties of rock in one schistose breccia will prove it to be of a different origin. This is more particularly the case when the rocks on one side of the breccia are all of one kind, and those on the other all of the same or of one different kind, and the fragments in the breccia distinct from either.

To determine whether a given breccia is of autoclastic origin or not, we must examine the fragments that it contains with as close a care as if it were a fossil, or a boulder in a glacial clay, and not be satisfied with calling it a grit or a slate, any more than in the parallel case with calling it a lamellibranch or a diorite. I have accordingly obtained a considerable number of fragments from numerous samples of schistose breccias, of which the following is a list:—Hill Series west of Snaefell: middle bend of the zigzag, Glen Auldyn; top-section in Glen Auldyn; base of the road north of Skyhill; Elfin Glen, Ramsey; Narradale, lower bend of the stream crossing the road; Albert-Tower Crags; Mountain Road, Ramsey; part of Druidale stream; Sulby Crags; Gob-y-Deigan Caves.

Of these, the examples denoted \*by the spaced type are the most instructive; and the best exposure of all is at Gob-y-Deigan Caves, as it is easily accessible at most tides, and well spread out over the foreshore and cliffs. But it is broken up, at its junction with the black slates or shales, into numerous angular faulted portions. Among the rocks here represented by isolated fragments, the following varieties may be recognized:—

(1) Many big pieces of hard laminated grit, like Agneash Grit, with an irregular waterworn appearance.

(2) Coarse-grained hard grit.

(3) Light, fine-grained grit, with irregular outline; seems to have been partly weathered before inclusion.

(4) Small specimens of hardened dirty clay-rock (compare A in fig. 12 of the Geological Survey-Memoir, p. 67).

(5) Unaltered beyond hardening, light shale, very brittle.

(6) Small piece finely laminated, and another coarser piece, closely resembling Snaefell Laminated Slate.

I find it impossible to conceive how such a set of rocks, so distinct one from the other, and so different from any that can be found around them, could be assembled in proximity to one another by any act of an autoclastic nature. It is the same with the other schistose breccias; the fragments that they contain are in the same way distinct among themselves, and not to be matched with the material which surrounds them in the solid state. In particular may be noted certain other cases; for example, in Sulby Crags the fragments in the Schistose Breccia are of various kinds mixed indiscriminately, while the fragments in the area between the Schistose Breccia and the contorted flags are all of one kind. In the Druidale section there is a coarse grit with ferruginous hollows, conspicuously unlike anything found elsewhere; and similarly, among the Hill Series, is found a large quantity of porous decayed

rock (sandstone, tuff or igneous), only to be matched in the Series itself.<sup>1</sup>

Regarding the second criterion of an autoclastic rock, that they will contain fragments of the overlying rock<sup>2</sup>: this involves our knowing which is the overlying rock, and thereby the order of succession. If the order of succession were that adopted in the Geological Survey-Memoir, it would be easy enough to prove that this criterion was satisfied; and one only wonders why no use was made of this in arguing for a 'crush-conglomerate.' But, when the order of succession is reversed, as in the present instance, the three uppermost strata have in places an obscure colour-banding, which is somewhat difficult to distinguish in a fragment from the lamination exhibited by beds below both the Schistose Breccia and the Barrule Slate.

Regarding the third criterion, that an autoclastic rock may generally be found graduating into a brecciated or semi-brecciated form: although there are numerous examples, I have found none graduating into anything else than their original form. Sulby Craggs are no exception to this; the nearest breccias are all of one kind, they are separated from the Schistose Breccia by a well-marked line, and the adjoining contorted flags are only bent, not broken; moreover, this is not the direction in which the structure is continued. The only case somewhat resembling an exception is the Hill Series west of Snaefell: on tracing the rounded sandstone-like pebbles from Ramsey up the strike to the Hill Series, we should find there such a majority like them, that we cannot be far from the centre whence this rock was dispersed; but these are mixed, at Ramsey, with many other varieties, which would prove too much.

From the failure of all the special characters of an autoclastic rock, I think we may conclude that none of those enumerated are of that character; the fragments which they contain have never been brought to their present position by two rocks shearing together under pressure, but consist rather of 'rock of an original fragmental character,' rendered schistose, and crushed out sometimes into smaller fragments, of which the cause is obvious in their later contortions.

There are also some peculiarities about the Schistose Breccia which carry strong weight in the same direction. (1) To call the rock a 'conglomerate' is to convey a wrong impression: it is very seldom that any of the fragments are rounded; the problem is rather to realize how they may possibly be removed from their original home with so little change, even with the freest motion,

<sup>1</sup> It may be noted in this connection that Prof. Watts, who assisted in the establishment of the term *crush-conglomerate*, writing three years later in his 'Geology for Beginners' (1898) says that they will differ from those deposited by water-action in three ways, of which No. 3 is 'the pebbles are all made of one kind of rock,' while a 'thrust-conglomerate will not differ much from a crush-conglomerate, except that two or three types of fragments may be present in it.' (*Op. cit.* p. 111.)

<sup>2</sup> See also J. E. Marr, 'Principles of Stratigraphical Geology' 1898, p. 81.

as, for example, in the Hill Series, in which the outlines are very distinct and clean, without any shading-off into the matrix. They are often soft enough to be scratched with the finger-nail, yet they end off in fine angles which the slightest shearing process would have broken away. (2) Again, in Gob-y-Deigan Caves, the large piece like Agneash Grit is much too hard to be touched by the matrix in which the fragments are embedded, or even by the black slates, and must have been rounded irregularly before being buried.

But, though the bulk of the Schistose Breccias, as at Gob-y-Deigan Caves, Druidale, Sulby, and Ramsey, and many others, show characters incompatible with 'crush-conglomerate' or auto-clastic rocks, there are also examples of the latter, as those figured in figs. 2-5 & 11 in Quart. Journ. Geol. Soc. vol. li (1895) pp. 568, 570-71, 582, which have been confounded with the Schistose Breccia.

The best, however, and most indubitable example of a true auto-clastic rock or fault-breccia, is the example described long ago by Henslow, which Mr. Lamplugh appears to have missed, as he says (Quart. Journ. Geol. Soc. vol. li, p. 563) of 'the headland south of Gob-y-Deigan':—

'It is here that the structure was noticed by Henslow. It is on the coast at Ballanayre Strand, where a stream runs over the surface of some angular fragments of clay-slate imbedded in a clay-slate paste . . . sufficiently apparent by the fragments assuming different tinges of colour.'<sup>1</sup>

These expressions could not possibly be used of the Gob-y-Deigan breccia, for there the fragments are perfectly distinct from the matrix at all states of the tide; but at Ballanayre it is 'curious' to see them only appear when wetted. In another part of the cliff some thin bands of grit are separated and drawn out like the well-known 'Belemnites' of the Nufenen Pass. The locality is probably a faulted one, as the Niarbyl Flags are seen nearly vertical in the sea close by, and the position of the slates is probably the same as that of the thin grit-bands, more nearly horizontal. In comparing these two localities, Ballanayre Strand and Gob-y-Deigan caves, we have an admirable illustration of the several characters which belong to each class of rock.

Other examples figured,<sup>2</sup> not from the band of Schistose Breccia, are from places where the rocks are so rapidly folded that parts of the same band divide into obviously-connected fragments, all of the same kind. These would probably be included among auto-clastic rocks; as also would the masses of unmixed fragments between the contorted flags and the boundary of the Schistose Breccia, on one side of the Sulby river, and a similar mass near the corner of the road on the other side. From none of these examples can anywhere passages be found into the mixed and widely-separated fragments of the Schistose Breccias.

In conclusion, I may be allowed to remark, that to make two

<sup>1</sup> Trans. Geol. Soc. ser. 1, vol. v (1820) p. 490.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. li (1895) pp. 570 & 582, figs. 3 & 11.

blades of grass grow where one grew before can in no way injure the credit of him who first made the first grass grow, and compared it with a 'crush-conglomerate.'

#### DISCUSSION.

MR. LAMPLUGH said that he strongly appreciated the kindly attitude of the Author, and recognized the pains which had been bestowed upon the investigation. But, after full consideration of the evidence brought forward by the Author, he found it necessary still to adhere to his previous interpretation, both of the succession and of the crush-conglomerate. In studying this extremely-complicated area the Author had placed far too much confidence in apparent dips, which had been shown to be misleading as indications of the sequence; and he had also called in faults to his aid, without any proof that these faults were of more consequence than the innumerable other fractures by which these rocks were traversed that apparently had no structural significance.

The speaker was well satisfied to find that three parts of the sequence proposed by him had been accepted by the Author, who, however, wished to reverse the order of the one remaining part by postulating a great unconformity, for which no acceptable evidence was forthcoming. All the facts known to the speaker were utterly opposed to the view that there could be an unconformity between the Lonan or Niarbyl Flags and the rest of the Manx-Slate Series.

As for the crush-conglomerate, the speaker did not feel called upon to defend the definitions of other workers: he relied entirely upon the field-evidence in the Isle of Man, which he held to be convincing for the 'autoclastic' origin of the fragmental beds. The disrupted strata were not homogeneous, but a mixture of laminated slates and gritty greywackés; and he failed to find any other material among the specimens exhibited on the table. The Author acknowledged the autoclastic structure in that portion of the crush-conglomerate where disruption was incomplete, but denied it for the portion in which the process had gone a step further.

The speaker admitted that there was room for further work in the Manx Slates, but he was doubtful whether the present attempt had really advanced our knowledge of this extraordinarily-difficult series.

MR. BARROW, who said that he had seen part of the area discussed, in company with the previous speaker, agreed with his interpretation of the nature and origin of the crush-conglomerate. But this rock differed somewhat from the commoner type, in which the matrix and the pseudo-pebbles had the same original composition. In the case described by Mr. Lamplugh, the pseudo-pebbles were embedded in a matrix originally of softer composition. The exceptionally-large scale on which the phenomenon had occurred, was probably due to the original nature of the rocks and their order of superposition. A thick bed of soft shale was underlain by a

comparatively-thin band of laminated sandy shale, or passage-material, which in turn reposed on a thick mass of sandstone. During the process of intense and complicated folding seen in the area, the passage-beds, owing to their less-resisting nature, were broken up and forced outward from the minor folds of the harder grit. The easily-yielding mass of still softer shale in front greatly facilitated this process, and many fragments of the passage-beds were forced into this shale.

Prof. WATTS pointed out some of the difficulties presented by the field-work in such a district as that in question. His microscopic investigation of the rocks collected by Mr. Lamplugh, showed that the individual pebbles were often beginning to exhibit a crush-structure which was undistinguishable from the general structure of the conglomerate. Further, he had been unable, after considerable search, to discover in the conglomerate any rock-fragment of a type different from the grits and slates found in immediate contact with the conglomerate itself.

Mr. CLEMENT REID thought, as the result of his recent examination of the Ordovician rocks in Cornwall, that true conglomerates (though sheared) could be distinguished from crush-breccias, if the softer material was ignored, and attention concentrated upon the fragments of whatever rock was hardest. In a sheared conglomerate the hardest pebbles still remained as pebbles, the softer material flowing past them; in a crush-breccia the hardest fragments, on the contrary, were the most angular, especially if they were rare.

The AUTHOR thanked the Fellows present for their reception of his paper, and the various speakers for their remarks. His friend Mr. Lamplugh spoke of the Lonan-Flag Series as occurring both below and above, which was, of course, different from his experience, and hard in any case to explain. Prof. Watts spoke of the fragments composing the Breccia as being broken up—which they very often were, as was natural; but this did not affect their original character.

17. *The RHÆTIC ROCKS of MONMOUTHSHIRE.* By LINSALL  
RICHARDSON, F.G.S. (Read March 22nd, 1905.)

[PLATE XXXII—VERTICAL SECTION.]

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I. INTRODUCTION.

IN Monmouthshire the Rhætic does not extend over a large area, and occurs only in the neighbourhood of Newport. Here it has attracted very little attention until quite recently, when the resurvey of the South-Wales Coalfield necessitated a fresh examination of the deposits, in order to complete the geology of Sheet 249 (New Series). Certain sections which came within the area were described, but hardly in sufficient detail, as the only lamellibranch recorded was *Modiola minima*.

In the present paper four new sections and three new exposures are described: the Goldcliff and Lis-Werry sections being included in the former category, because hitherto comparatively little was known about them.

II. DESCRIPTION OF THE SECTIONS.

(A) Goldcliff.

About  $3\frac{1}{2}$  miles to the south of Llanwern Station, and rising from the alluvial flat called Caldicot Level, is the little inlier of Keuper, Rhætic, and Lower Liassic rocks denominated Goldcliff. Although the occurrence here of Rhætic and Lower Lias has long been known to geologists, details of the section have been difficult to obtain; and, until the present time, it has been possible to investigate only the basement-beds of the Rhætic and those at the base of the Lower Lias. This is due to the fact that the cliff had to be faced with masonry, in order to continue the sea-wall.

About the year 1824 Buckland & Conybeare noted the occurrence



here of Lias and Red Marl, but remarked that the section 'is now almost entirely concealed by a high sea-wall erected in front of it.'<sup>1</sup>

In a paper communicated to the British Association,<sup>2</sup> and again in his 'Note-Book of an Amateur Geologist,'<sup>3</sup> J. E. Lee drew attention to the occurrence of a bone-bed in the Keuper Marls; but apparently it did not occur to him that the fact was of any interest, for it was not until 1888 that it was remarked by Mr. Horace B. Woodward, F.R.S., that Lee had

'omitted to point out that the Bone-Bed there occurs beneath 3 feet of the greenish-grey marls, which are thus shown to be intimately linked with the *Avicula contorta*-Shales above.'<sup>4</sup>

In a recent memoir published by the Geological Survey, Mr. A. Strahan, F.R.S., has given some interesting and valuable details concerning the junction of the Rhætic and Keuper, and commented upon the fact that

'the base of the Rhætic is conspicuous and sharply defined, and the green marls below it exhibit the cuboidal weathering so commonly seen in the Keuper. The occurrence in them, however, of a "bone-bed" is quite exceptional.'<sup>5</sup>

It will be observed from the foregoing quotations that, although certain details concerning both the Rhætic and the Lower Lias have been recorded, the description nevertheless remained very incomplete, as nothing was known about the middle portion of the series. Therefore it was fortunate, when I visited the section, to find that a breach in the wall was being repaired, and that the sequence of deposits, from about where Mr. Strahan's record ended, up to the Lower Liassic beds, was visible. Mr. Strahan gave details of the deposits up to, and inclusive of, that numbered 15 in the present record; but, when the writer visited the locality, that bed, according to the foreman, had just been hidden by the masonry. Many pieces, however, were lying about, so that the rock could be examined for fossils. Owing to the interest which is attached to this section, the complete record is appended (Pl. XXXII).

Concerning the Lower Lias no particular comment is necessary: the faunal and lithic characters of the beds are similar to the equivalent beds at Sedbury Cliff—indeed, they correspond almost bed for bed. According to a detailed record of the Lower Liassic beds in the Sedbury-Cliff section that I made, the first appearance of *Psiloceras planorbis* was in the deposit corresponding to the stratum which should come immediately above the deposit numbered 1 in the section accompanying this paper (Pl. XXXII).

As the ground at Goldcliff rises somewhat away from the sea-wall,

<sup>1</sup> Trans. Geol. Soc. ser. 2, vol. i (1824) p. 305.

<sup>2</sup> Rep. Brit. Assoc. (Brighton) 1872, Trans. Sections, p. 116.

<sup>3</sup> London, 1881, p. 72 & pls. clxxi-clxxii.

<sup>4</sup> Proc. Geol. Assoc. vol. x (1888) p. 538.

<sup>5</sup> Mem. Geol. Surv. 'The Geology of the South-Wales Coalfield' pt. i: 'The Country around Newport, Monmouthshire' 1899, p. 75.

the *planorbis*-zone must be present in the hill; and, as a matter of fact, Mr. Horace B. Woodward has recorded the zonal ammonite. So far as could be seen, however, the beds near the barn (where these measurements were taken) were of pre-*planorbis* date—a deposit better known as the *Ostrea*-Beds. Near Llanwern Station these beds, together with the *planorbis*-limestones, are quarried for the supply of lime-kilns.

The topmost bed of the Rhætic is an interesting stratum. Its upper surface is conspicuously waterworn, while in the superincumbent shales are often found small pebbles derived from this bed; this is evidently, therefore, the horizon at which the line of demarcation between the Rhætic and the Lower Lias should be drawn. The *Estheria*-Bed was located, but no remains of *Lycopodites lanceolatus* were observed. However, it may be advisable to state that they do occur in association with the *Estheriæ* at certain localities. I have found this to be the case at Garden Cliff and Redland (Bristol). In a hand-specimen of the bed from the latter locality (and now in my collection) numbers of the phyllopod occur intermingled with the plant-remains. A cast of *Schizodus Ewaldi* was found in the *Estheria*-Bed: a somewhat high horizon for this lamellibranch.

The various beds of the Lower Rhætic (*contorta*-age) much resemble their equivalents at Aust Cliff. More limestone-bands occur in the deposit of this date in the Newport district, than in that to the north of Purton Passage. Although, from a study of this section alone, they seemed to be intermittent, similar limestones are found occupying the same stratigraphical horizons throughout the district; but, of course, in some places they are more developed than in others. The bed numbered 13 is the most persistent in the Goldcliff section, and represents the *Pleurophorus*-Bed of Aust Cliff. Palæontologically, the most interesting fact is the abundance of *Cardium cloacinum*, Quenstedt. This fossil escaped identification for a considerable time, but it was obtained many years ago by that successful and ardent collector, Charles Moore, from the Rhætic exposed in the railway-cutting at Willsbridge, near Bath, and was recorded in his section as *Cardita*.<sup>1</sup> The specimens of *Protocardium Philippianum* in Bed 6 are very well-preserved, for fossils from the shales.

The deposit which has caused the Goldcliff section to become so well-known is the Bone-Bed in the Green Marls. The explanation suggested by Lee, and accepted by Mr. Strahan, is that

‘the bones occur in what seem to have been sinuous and irregular runlets excavated in a mud-flat. . . . The runlets became filled in with coarse quartz-sand mixed with many scales and teeth of fish[es], and by the hardening of their contents now resist denudation better than the marl in which they were enclosed. They are well-shown in the foreshore at the foot of the wall, about

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<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 498.

5 feet below the base of the Rhætic beds; they vary from 3 to 12 inches in width, and can sometimes be traced for 7 or 8 yards. Among the fish[es], *Gyrolepis Alberti*, Ag., and *Hybodus minor*, Ag., have been recognized by Mr. E. T. Newton: *Saurichthys*, also, is quoted by Mr. Lee.<sup>1</sup>

Mr. Horace B. Woodward<sup>2</sup> (as I have already mentioned) has commented upon the importance of finding a bone-bed containing remains of Rhætic vertebrates in the 'Tea-Green Marls,' since, in his opinion, it links the deposits in which they occur with the Rhætic. The mode of formation, however, of these ramifying veins of quartz-sand is obviously not that under which a continuous stratum was laid down. They are certainly distributed, so far as can be seen, along a definite stratigraphical horizon, but the suggestion that the material accumulated in runlets in a mud-flat is not altogether satisfactory, although it very nearly explains the phenomenon.

### (B) Bishton.

To the east of Newport a considerable tract of country is composed of Rhætic and Lower Liassic rocks. In this area are several excellent sections, which have hitherto remained undescribed. The first to be noticed is at Bishton. At the northern end of the village a lane leaves the Llanmartin road on the right, and leads to Poolhead Cott. This lane is now frequently occupied by a stream, but the steep banks afford a magnificent and accessible section of the 'Tea-Green Marls,' the Lower Rhætic, and most of the component beds of the Upper: the only deposits of which it is a little difficult to obtain measurements being those immediately above and below the *Estheria*-Bed. *Estheria* was not recorded here, but it was observed at Goldcliff, and the lithic structure of the limestone is identical.

As will be noticed from the following record, this section much resembles that at Goldcliff:—

LOWER LIAS. Limestones and Clays.		Feet inches.	
UPPER RHÆTIC.	1 a. Cotham - Marble equivalent. A smooth-textured limestone with bluish centre .....	0	6
	b. Clay-parting .....	0	0½
	c. Limestone, hard, crystalline .....	0	2
	2. Shales, yellowish, marly .....	2	0
	3. Limestone: <i>Estheria</i> -Bed. Sometimes a creamy-yellow, smooth-textured limestone with bluish patches, and at others a hard nodular limestone with 'aborescent' markings.....	0	4
	4. Shales, greenish and yellowish, marly.	1	5

<sup>1</sup> Mem. Geol. Surv. 'The Geology of the South-Wales Coalfield' pt. i: The Country around Newport, Monmouthshire' 1899, pp. 75-76.

<sup>2</sup> Proc. Geol. Assoc. vol. x (1888) p. 538.

(Bishton section, continued.)

		Feet inches.	
LOWER RIETIC.	5 a. Shales, black, becoming light-coloured near the top .....	3	4
	1. Shales, grey, with earthy limestone on the top .....	0	3
	2. Fibrous carbonate of lime ('beef') .....	0	0½
	3. Limestone, hard, dark, intermittent .....	0	2
	4. Shales, grey and black, with a half-inch layer of limestone about the centre .....	0	1½
	5. Fibrous carbonate of lime ('beef') .....	0	0½
	6. Shales, grey and black: 3 to 5 inches .....	0	4
	7. Yellow earthy layer: ¼ to ¾ inches... ..	0	0½
	8. Shales, black .....	1	10
	9. Limestone, grey, earthy, passing into a grey nodulated marl .....	0	8
	10. Shales, black, thinly laminated .....	1	4
	11. Sandstone, very pyritic .....	0	1
	12. Shales, black, laminated .....	1	3
	13. Limestone, dark - grey, slightly pyritic .....	0	3
	14. Shales, black, thinly laminated at the top .....	2	2
UPPER KEUPER.	a. Quartz-sand, rich reddish-brown with hard layer above .....	0	2
	b. Yellow clay .....	0	1
	c. Quartz-sand, black .....	0	2
	d. Limestone, hard, dark-grey, slightly arenaceous, with small rolled fragments of green marl. ....	0	3
	I. 'Tea-Green Marls': yellowish and greenish-grey marls .....	12	0
	II. Red Marls.		

The hard dark limestone 5 b (3) is very fossiliferous, and the shells are excellently preserved—especially the specimens of *Placunopsis alpina* and *Schizodus Ewaldi*.

Continuing now along the Llanmartin road, a barn will be noticed on the left-hand side, and in a hollow near by a Rhætic sandstone-bed is exposed. Owing to the formation of travertine, however, it is difficult to obtain any reliable details.

A little farther on, there is a cottage on the right; and a short distance beyond again an exposure, showing, in descending order, black shales, a hard blackish limestone crowded with well-preserved specimens of *Cardium cloacinum*, and less commonly with *Schizodus Ewaldi*, *Protocardium Philipianum*, *Placunopsis alpina*, and *Gyrolepis Alberti*, while below are black shales. The limestone-bed corresponds to 5b(3) at Bish-ton. Another exposure a little farther on in the direction of Llanmartin shows the Cotham-Marbleequivalent, with pale marly shales below and hard light-brown paper-shales above. Immediately below the Cotham-Marble equivalent is a thin bed of limestone, full of *Modiola minima*.

About a quarter of a mile south-west of Llanmartin the road passes through a cutting, in the north-

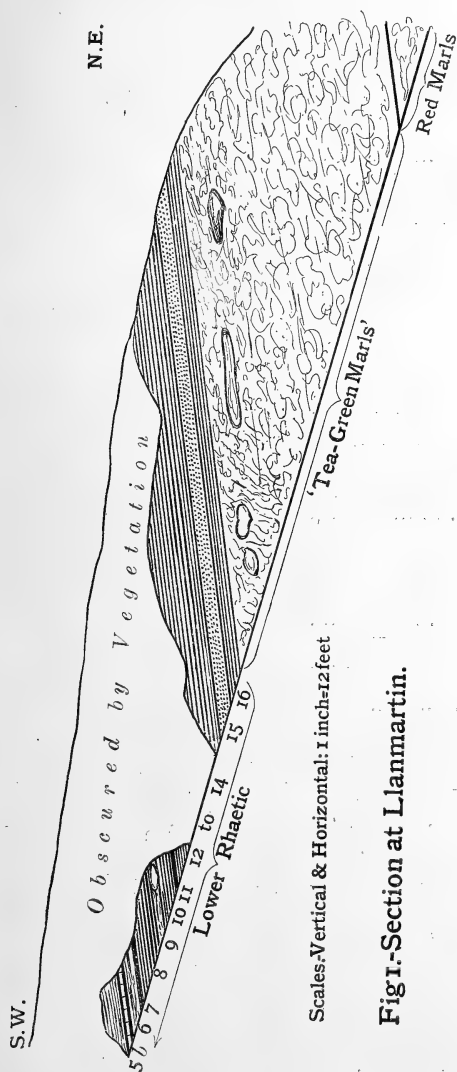


Fig. 1.—Section at Llanmartin.

western bank of which the following section is exposed (see also fig. 1):—

## (C) Llanmartin.

		Feet inches.		
LOWER RHÆTIC.	5 b	1? Shales, black.		
		3. Limestone, with layer of 'beef' on the under surface, very earthy.	0 3	<i>Pteria contorta.</i>
		4. Shales, black	0 3	
		5. Yellow earthy deposit	0 0½	
		6. Shales, black	0 7	
		7. Yellow earthy layer	0 1	{ <i>Pectens (Chlamys)</i> , much crushed; fish-scales.
		8. Shales, black	1 9	
		9. Limestone, earthy, passing into an indurated marl..... about	0 5	
		10. Shale, black	1 3	
		11. Sandstone, micaceous, weathering into a rich yellow sand	0 1	<i>Schizodus (?)</i> .
		12 to 14. Shales, black; estimated at	3 6	
	15	a. Quartz - sand. Immediately above are two thin layers of yellow clay, with a ¼-inch seam of quartz-sand interpolated ...	0 3½	
		b. Greenish clay, with sandstone-layer at the base	0 2½	
		c. Coarse sand	0 4	
		d. Greenish clay		
		e. Grit, coarse, weathering into a quartz-sand	0 2	
	16	a. Clay, greenish	0 6	
		b. Thin seam of quartz-sand	0 0½	
		c. Greenish-grey and black clay ...	0 5	
UPPER KEUPER.	I. 'Tea-Green Marls.'			
		a. Pale greenish-grey and yellowish marls	1 2	
		b. Band of marlstone, weathering somewhat nodular	0 8	
		c. Pale greenish-grey and yellow marls	about 12 2	
	II. Red Marls.			

Near Milton there are two exposures, one of which may be distinguished as the Llanwern section, in order to prevent confusion. It is situated three-quarters of a mile north-by-east of Llanwern railway-station, and shows the junction of the Rhætic and the Keuper: the beds at this horizon resembling those exposed at Bishton, rather than the beds exposed at Llanmartin.

## (D) Llanwern.

		Feet inches.		
LOWER RHÆTIC.	{	14. Shales, black, with a few gritty layers near the base.		
		15. Quartz-sand, rich reddish-brown at the top, and dark-chocolate below	0 8	<i>Acrodus minimus.</i>
		16. Grit, extremely-hard masses in places; in others, thinner and laminated	0 5	Wood; scales of <i>Gyro-lepis</i> .
UPPER KEUPER.	{	I. 'Tea-Green Marls' .....	about 13 6	
		II. Red Marls.		



apparently to the Llanmartin section (p. 380), in that there is a deposit below the grit of *contorta*-age—distinguished as bed 16 at Llanmartin.

Near Bishopool, the escarpment formed by the Keuper and the Rhætic, and capped by the Lower Lias, is very conspicuous; and at Pinkham Hill it is breached by a road-cutting.

### (F) Bishopool.

	Feet	inches.
14. Shales, light-coloured, clayey, with two thin gritty seams passing up into black clayey shales.		
15. { <i>a.</i> Quartz-sand, rich reddish-brown and black.	0	9
<i>b.</i> Sandstone-layers and shaly matter .....	0	7
<i>c.</i> More massive layers: <i>Modiola minima</i> ...	0	3
16. Shales, black, with sandy layers .....	0	4
I. 'Tea-Green Marls.' Pale-yellow: visible.....	5	0

The last section to be described is at Lis-Werry, near the well-known quarries in the Lower Liassic limestones: indeed, the cutting in which the Rhætic beds are exposed was made for the road to the quarry. This section also has received attention from Mr. Strahan,<sup>1</sup> but the following record is much more detailed. The Lower Liassic beds are given on that writer's authority.

### (G) Lis-Werry.

	Feet	inches.	
LOWER LIAS.	{ Limestones, irregular, with partings of clay and shale .....	8	6
	{ Limestones, more even, with very thin partings of shale .....	8	0
	{ Paper-shales .....	3	6
	{ 1. Limestone, blue-hearted but weathering white; the upper and lower parts shelly, with <i>Modiola minima</i> abundant, the middle part smooth-textured and pale; faint arborescent markings in places (equivalent to Cotham Stone). [ <i>teste</i> A. Strahan]	1	0
UPPER RHÆTIC.	{ 2. Pale-brown, thinly-laminated shales.	1	4
	{ 3. Pale greyish-green, earthy nodular limestone passing into shale .....	1	0
	{ 4. Pale greyish-green marly shales: about...	3	6
			{ <i>Cardinia</i> sp., <sup>2</sup> <i>Cardium cloacinum</i> , <i>Protocardium Philipianum</i> , <i>Modiola minima</i> , <i>Gyrolepis</i> (scale).

<sup>1</sup> Mem. Geol. Surv. 'The Country around Newport' 1899, p. 75.

<sup>2</sup> The form identified as *Cardinia concinna* (Sow.) aff. *regularis*, Terq., Quart. Journ. Geol. Soc. vol. lx (1904) p. 204 & pl. xviii, fig. 4.



(Lis-Werry section, continued.)

Feet inches.

LOWER RHÆTIC.	5 a.	Shales, black .....	about 4	6	{ Same fossils as in Bed 4, with the addition of <i>Schizodus Ewaldi</i> and <i>Pteria contorta</i> .
	5 b.	Limestone, dark-grey, earthy; 'beef' on the upper surface. Immediately below these are occasionally present hard nodules with <i>Pecten (Chlamys) valoniensis</i> and <i>Pteria contorta</i> adhering to them: very variable deposit .....	0 3		
	6.	Shales, black .....	1 1		
		Limestone, dark: selenite.....	0 1		<i>Pecten (Chlamys) valoniensis</i> .
	7.	{ Clay, black, indurated and arenaceous in places: .....	0 2		<i>Schizodus Ewaldi</i> and many shell-fragments.
		Limestone, dark.....	0 1		<i>Gyrolepis Alberti</i> (scales and teeth?).
	8.	Shales, black .....	3 0		
	9.	Yellowish-brown earthy limestone, with 'beef' on the top.....	0 3		
	10.	Shales, black and brown .....	4 0		{ <i>Pteria contorta</i> , <i>Schizodus Ewaldi</i> , <i>Cardium cloacinum</i> .
	11.	Limestone, earthy, hard in places: 2 to 4 inches.....	0 3		<i>Gyrolepis Alberti</i> .
	12.	Shales, black and brown .....	1 3		
	13.	Yellow, ferruginous layer .....	0 0½		
	14.	Shales, black and brown .....	2 0		<i>Schizodus Ewaldi</i> .
UPPER KEUPER.	15.	{ a. Sandstone, coarse, weathers into a quartz-sand, deep-red but occasionally yellowish: about	0 4		
		b. Shales, black and brown, with gritty layers .....	1 0		
		c. Sandstone-beds passing down into brown and black shales, with thin gritty layers.....	0 6		Casts of a lamellibranch.
		I. 'Tea-Green Marls.' Greenish and yellowish marls .....	13 0		
		II. Red Marls, with greenish patches .....	seen 15 0		

Some of the beds in this section are very fossiliferous, especially the shales 4 & 5 a, as is usually the case. *Desmacanthus cloacinus* was obtained from one of the beds by J. E. Lee.<sup>1</sup>

The Rhætic is poorly exposed in the river-bank, and along the railway at Maes-glâs.

### III. CONCLUSION.

In the Newport district—except perhaps at Goldcliff—the plane of separation between the 'Tea-Green Marls' (Keuper) and the black shales of the Rhætic is very definite. As Mr. Strahan wrote:

'The plane itself is not infrequently accompanied by an inch or two of conglomerate, consisting of quartz-pebbles, rolled teeth and bone-fragments

<sup>1</sup> 'Note-Book of an Amateur Geologist' 1881, p. 35 & pl. xii

which, without indicating an actual unconformity, points to an abrupt change of physical conditions. Taken in connection with the sudden appearance above it of the Rhætic fauna, it suggests the first complete invasion of the area by the Rhætic sea.<sup>1</sup>

Mr. Strahan also observed that the invasion 'seems to have been sudden.' Probably the phenomena which suggested this view are due to the Rhætic ocean spreading with comparative rapidity over what were—previous to its ingression—flats of 'Tea-Green Marl.' To the south, around Cardiff, lay a stretch of water, either an extension of the Keuper inland sea which had been reduced by evaporation; or a lake, which would imply that evaporation had caused a still greater reduction in the volume of water in the Keuper sea, and probably had produced isolated patches of water. In these areas deposition would have proceeded continuously, and therefore in such the most complete sequence from the Keuper to the Rhætic should be observable.

The notation adopted in this paper for the various beds is similar to that which I employed when describing the sections in North-West Gloucestershire, Worcestershire, and Sedbury Cliff, but it must be understood that the correlation of the beds seen in the several sections is only approximate.

The upper surface of the Cotham-Marble equivalent at Goldcliff is conspicuously waterworn, and at the base of the superincumbent shales are pebbles of limestone derived from this bed. There is certainly a non-sequence here; between the paper-shales and the Cotham-Marble equivalent should come the White Lias.

For assistance in the field-work my thanks are due to my friend Mr. E. Talbot Paris.

#### EXPLANATION OF PLATE XXXII.

Vertical section at Goldcliff, near Newport (Monmouthshire),  
on the scale of 4 feet to the inch.

#### DISCUSSION.

MR. STRAHAN said that he wished to testify to the value of the work accomplished by the Author, in identifying the various palæontological horizons in the Rhætic group in localities where that had not yet been fully done. He was unable to agree that there was any overlapping of the 'Tea-Green Marls' by the *Avicula contorta*-shales. Those marls varied but little in thickness over the whole region. He had been unable to identify the 'Grey Marls' of Etheridge, and doubted whether any such subdivision of the 'Tea-Green Marls' could be made. This, however, in no way impaired the value of the palæontological part of the paper.

<sup>1</sup> Mem. Geol. Surv. 'The Geology of the South-Wales Coalfield' pt. i: 'The Country around Newport' 1899, p. 71.

ICAL SECTION AT GOL = 4 feet.

Marble  
ent  
ed

Hidden by the sea-wall now (1904)

RHÆTIC SERIES.

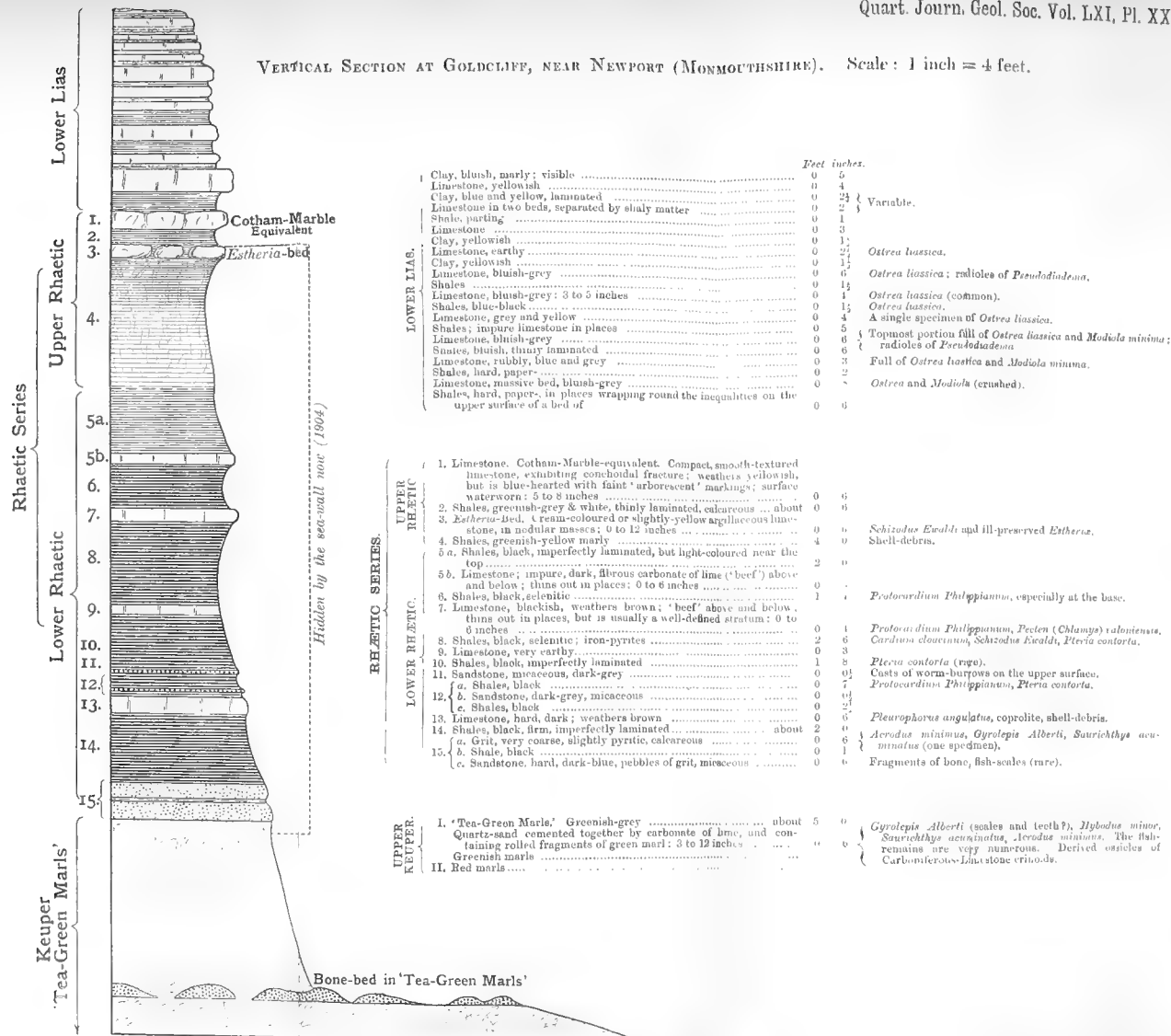
- LOWER LIAS.
- (Clay, bl
  - Limesto
  - Clay, bl
  - Limesto
  - Shale, p
  - Limesto
  - Clay, ye
  - Limesto
  - Clay, ye
  - Limesto
  - Shales
  - Limesto
  - Shales, (common).
  - Limesto of *Ostrea liassica*.
  - Shales; all of *Ostrea liassica* and *Modiola minima*;
  - Limesto *Modioladema*.
  - Shales, *Modiola minima*.
  - Limesto *Modiola minima*.
  - Shales, (crushed).
  - Limesto
  - Shales, upp
- UPPER RHÆTIC.
- 1. Lime
  - lu
  - bu
  - wi
  - 2. Shal
  - 3. *Esth*
  - stand ill-preserved *Estheria*.
  - 4. Shal
  - 5 a. Shi
  - to
  - 5 b. Lin
  - an
  - 6. Shal *Oppianum*, especially at the base.
  - 7. Lime
  - th
  - 6 *Oppianum*, *Pecten (Chlamys) valoniensis*.
  - 8. Shal, *Schizodus Ewaldi*, *Pteria contorta*.
  - 9. Lime
  - 10. Shal (re).
  - 11. Sandrows on the upper surface.
  - 12. { a. *Oppianum*, *Pteria contorta*.
  - b. S
  - c. S
  - 13. Lime *tatus*, coprolite, shell-débris.
  - 14. Shal *Gyrolopis Alberti*, *Saurichthys acu-*
  - a. G
  - b. S
  - 15. { c. S, fish-scales (rare).
- UPPER KEUPER.
- I. 'Tea (scales and teeth?), *Hybodus minor*,
  - Quar *minatus*, *Acrodus minimus*. The fish-
  - ta *minatus*, *Acrodus minimus*. The fish-
  - Green numerous. Derived ossicles of
  - II. Red limestone crinoids.

Bone-bed in 'Tea-Green





VERTICAL SECTION AT GOLDCLEIFF, NEAR NEWPORT (MONMOUTHSHIRE). Scale: 1 inch = 4 feet.





18. *The RHÆTIC and CONTIGUOUS DEPOSITS of GLAMORGANSHIRE.*

By LINSALL RICHARDSON, F.G.S. (Read May 24th, 1905.)

## [PLATE XXXIII—FOSSILS.]

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## I. INTRODUCTION.

IN the autumn of 1904 I made, in company with my friend, Mr. E. Talbot Paris, a detailed examination of the Rhætic and contiguous deposits of Monmouthshire and Glamorganshire. The results of my investigations in the former county have already been made known,<sup>1</sup> and it now remains to record those in the latter.

Less than four years have elapsed since the officers of the Geological Survey completed the re-survey of the Secondary rocks of Glamorganshire; and that part of the memoir on 'The South-Wales Coalfield' which deals with the Bridgend district was only issued to the public last January. This being the case, it might be thought that but little of interest would have remained to be noticed in the present communication. However, whereas the officers of the Survey were mainly concerned in the mapping of the deposits, my attention was directed in most cases to the accumulation of facts bearing upon the physical geography of the Rhætic Epoch.

On a previous occasion I communicated to this Society a theory, to account for the geographical distribution in North-West

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 374-84.

Gloucestershire and Worcestershire of certain beds at the base of the Rhætic Series. I then stated that

‘there is evidence to suggest that there were earth-pressures at work at the close of the Keuper Epoch, which caused the deposits to be thrown into slight synclinal and anticlinal flexures. In the depressed areas the earlier deposits of the Rhætic were laid down, and successive overlap on to the marls seems to have taken place.’<sup>1</sup>

My reasons for suggesting this explanation for the phenomenon were as follows. Throughout North-West Gloucestershire and Worcestershire the component deposits of the Rhætic are remarkably persistent. There were slight earth-movements towards the close of the *Pteria* (*Avicula*)-*contorta* age, it is true, which affected the persistency of one or two beds; but the cause for their irregularity is so obvious, that it does not influence the matter under discussion. Once below a certain stratum, however, such persistency is not to be observed. That stratum happens to be full of saurian- and fish-remains at certain localities, on which account it has been denominated the ‘Bone-Bed.’ Therefore I employed this term, or that of ‘Bone-Bed equivalent,’ according as the circumstances demanded. The geographical distribution of these infra-Bone-Bed deposits appears to me to be, at present, satisfactorily explained only by the theory that I have formulated.

For some years previous to the publication of the above-mentioned paper, I had come to the conclusion that

‘when the Rhætic ocean gained access to the British area it spread over an undulating expanse of Keuper Marls. In some areas, however, . . . lakes probably existed, and it would be in these areas that the complete sequence from the Keuper to Rhætic deposits should be looked for. The section of deposits formed under the conditions stated would be essentially of transitional nature, as at Watchet; but where the Rhætic ocean spread over the surrounding ground a non-sequence would result. Thus, at the present time, the junction-line would appear sharply defined; there would be no transitional signs, and practically no erosion.’<sup>2</sup>

A stretch of water, probably of considerable dimensions, extended into the Lavernock district, and therefore, according to my theory, transition-beds should be present. Such is the case: the transition-beds are the ‘Grey Marls’ (*pars*) of the late Robert Etheridge. This term would have been a convenient designation for the beds, had it not been generally misinterpreted. But, as such is the case, it appears desirable to replace it by the term ‘Sully Beds,’ after the locality where the most interesting development can be studied.

## II. THE SULLY BEDS.

In his very interesting memoir of Robert Etheridge, Mr. H. B. Woodward, F.R.S., drew attention to the fact that the ‘Grey Marls’ and ‘Tea-Green Marls’ of Etheridge were distinct deposits.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lx (1904) p. 356.

<sup>2</sup> *Ibid.* p. 357.



'Etheridge,' he wrote, 'originally placed them [that is, the 'Tea-Green Marls'] in the Keuper, and distinguished them from the Grey Marls which frequently form the base of the Rhætic.'<sup>1</sup> In support of this interpretation of Etheridge's remarks, Mr. Woodward quoted from the paper published by Etheridge in the Proceedings of the Cotteswold Naturalists' Field-Club. In that paper, Etheridge recorded this sequence:—'alternating bands of grey and red fissile and conchoidal marls (No. 1 in section), apparently here containing no fossils';<sup>2</sup> and then, above these 'Tea-Green Marls' a series of Grey Marls. The point upon which Mr. Woodward naturally laid stress was that Etheridge denominated the lower of these two series the 'Tea-Green Marls': not the upper, which he distinguished by the name of 'Grey Marls.' As will be seen by referring to his section at Garden Cliff, the beds that he wished to be called the 'Tea-Green Marls' are not those to which the term has been restricted by most authors. Etheridge's suggestion with regard to these 'Tea-Green Marls' of his at Garden Cliff was, that although they did differ lithically, they nevertheless corresponded to certain beds at Watchet, Penarth, and Puriton,

'at which places,' he wrote, 'I have termed them "Tea-Green Marls," from the peculiar hue of the freshly-fractured shales when exposed, and the constancy of their conditions.'

The 'Grey Marls' (the upper strata of which are here designated the Sully Beds) above he regarded as belonging to the Rhætic, because they contained fish-remains.

Mr. Woodward's explanation of Etheridge's conclusions is very satisfactory, because I had been compelled to adopt the view that there were marls which were Rhætic, and again such as were Keuper. But, while agreeing with Etheridge that this was the case, I fail to see any evidence, either palæontological or stratigraphical, why the marls below what I have called the 'Tea-Green Marls' at Garden Cliff (which there come immediately below the Rhætic Black Shales)<sup>3</sup> should be regarded as the equivalent of certain beds which Etheridge admitted were lithically different at Penarth, Watchet, and Puriton. Is it not much more probable that the 'Grey Marls'—certainly that the fossiliferous portion of them, namely, the Sully Beds—of the Lavernock and Watchet districts—are not represented in North-West Gloucestershire and Worcestershire; and that they are only found within the limits of those areas which were submerged at the time when the Rhætic ocean gained access to the British low-lying country?

These Sully Beds will be again dealt with after the sections in Glamorganshire have been described.

<sup>1</sup> Proc. Bristol Nat. Soc. ser. 3, vol. x (1903-04) p. 183.

<sup>2</sup> Vol. iii (1865) pp. 220, 221.

<sup>3</sup> Proc. Cottesw. Nat. F.-C. vol. xiv (1903) table iii, facing p. 174.

## III. DESCRIPTION OF SECTIONS.

## i. The Penarth District.

In the Penarth district are included the outliers of Leckwith, Penarth, Lavernock, and Cross: all capped by Lower Liassic deposits.

The Penarth section, it is almost superfluous to state, is a classic one, as the name of the locality suggested to Murchison an alternative denomination for the Rhætic—the Penarth Beds. It is unnecessary, for the present purpose, to discuss all that has been written on this far-famed section; but, for the convenience of those who desire to study the literature, references are given in a footnote.<sup>1</sup>

The cliff-section at Penarth is disappointing. It is true that there is a faulted syncline which has brought the Rhætic to the foot of the cliff, but recently (August 1904) a slip has obscured the greater part of the section which was available. Accordingly, if anyone wishes to obtain details of value, it is necessary (to quote Mr. H. B. Woodward) 'to climb an almost perpendicular cliff.' Fragments of the several hard beds can be seen on the beach, and from an examination of their lithic structure it is often possible to state that such and such a bed is present in the cliff-section; but that is about all. The details recorded by Bristow and Etheridge were obtained in a railway-cutting; and at the present time several such exposures are available, especially at Penarth Docks.

It is not necessary, however, to climb Penarth Head, for at Seven Sisters' Bay the base of the Rhætic is within 3 feet of the beach; while at Lavernock Point the beds are even more accessible and convenient to examine than at Garden Cliff, Westbury-on-Severn. The section at Seven Sisters' Bay is very similar to that at Lavernock; if anything, the beds are a little thicker, and continue to increase in thickness until Penarth Head is reached. At Penarth Head Mr. Woodward has noticed a band of limestone, which reminded him of the Cotham Marble; and I have observed a similar bed—which probably represents the Sun-Bed of the White Lias—at Lavernock (p. 393) and Barry (p. 398). On the beach at Seven Sisters' Bay were pieces of limestone, probably from the same horizon, that had been bored by *Lithophagus* (*Lithodomus*, Cuvier) and encrusted with *Plicatula intus-striata*, Emmrich.

<sup>1</sup> H. T. De la Beche, Mem. Geol. Surv. vol. i (1846) p. 253; T. Wright, Quart. Journ. Geol. Soc. vol. xvi (1860) pp. 381–82; W. V. Guise (Presidential Address, 1863), Proc. Cotteswold Nat. F.-C. vol. iii (1865) pp. 117, 118; H. W. Bristow, Geol. Mag. vol. i (1864) p. 236, & Rep. Brit. Assoc. 1864 (Bath) Trans. Sections, p. 50; R. Etheridge, Trans. Cardiff Nat. Soc. vol. iii (1870–71) pt. ii, p. 39; Bristow & Etheridge, Geol. Surv. Vertical Sections, 1873, Sheet 47; T. Wright, 'Monogr. Lias Ammon. Brit. Is.' Pal. Soc. 1878, p. 10; J. Storrie, Trans. Cardiff Nat. Soc. vol. xiv (1882–83) p. 100; H. B. Woodward, Proc. Geol. Assoc. vol. x (1888) p. 529, & Rep. Brit. Assoc. 1888 (Bath) p. 900; J. Storrie, Trans. Cardiff Nat. Soc. vol. xxvi (1894) p. 105; A. Strahan & T. C. Cantrill, 'The Geology of the South-Wales Coalfield: Part iii—The Country around Cardiff' Mem. Geol. Surv. 1902, p. 59–63.

## (A) Lavernock.

The section at Lavernock is certainly one of the finest in the country of the beds under consideration. The Rhætic can be studied in the foreshore and cliffs of the deeply-indented little bay immediately to the north of Lavernock Point; the White Lias and the *Ostrea*-Beds succeed; while round the Point, and as far as St. Mary's-Well Bay, Sully, are the *planorbis*-, *angulata*-, and *Bucklandi*-beds (*pars*), arranged in a gentle syncline. At St. Mary's-Well Bay, the Rhætic again makes its appearance. North of Lavernock Point the strata rise into a gentle anticline, with the result that the Keuper makes its appearance. Thus Keuper, Rhætic, and Lower Lias can all be examined in this unrivalled coast-section.

Although brief reference has been made to the section by several authors,<sup>1</sup> it has not received sufficient attention. The most complete record is that given by Bristow; but he mentioned comparatively few fossils. For several reasons, a very detailed section has been appended to the present paper (facing p. 392).

The Keuper Red Marls are of the usual type: dark-red marls, with greenish-grey zones. Above come the 'Tea-Green Marls,' having, according to my measurements, a total thickness of 33 feet 4 inches. The most interesting feature in connection with these marls is the occurrence in them of gypsum—a mineral that is particularly rare in North-West Gloucestershire and Worcestershire. Indeed, I have not found it in the marls of the sections which I have studied in that district in any appreciable quantity.

Above the 'Tea-Green Marls' come the Sully Beds—a portion of Etheridge's 'Grey Marls.' The line of demarcation between the two series of deposits is necessarily an arbitrary one. The peculiar lithic characters of the Sully Beds at Lavernock, and the fact that John Storrie found '....some remains of the great Labyrinthodon, *Mastodonsaurus*....', in association with a number of small teeth of *Sphærodus*, a mandible believed to belong to *Palæosaurus*, two teeth belonging to the same dinosaur, and remains of *Trematosaurus*, about 6 feet below the Rhætic 'fish-bed,'<sup>2</sup> all support the conclusion that the Sully Beds are more intimately connected with the Rhætic than with the Keuper. The most useful evidence in support of this contention, however, was obtained at St. Mary's-Well Bay (Sully), Cross, and Cadoxton; as will be shown later (pp. 395, 396, & 399).<sup>3</sup>

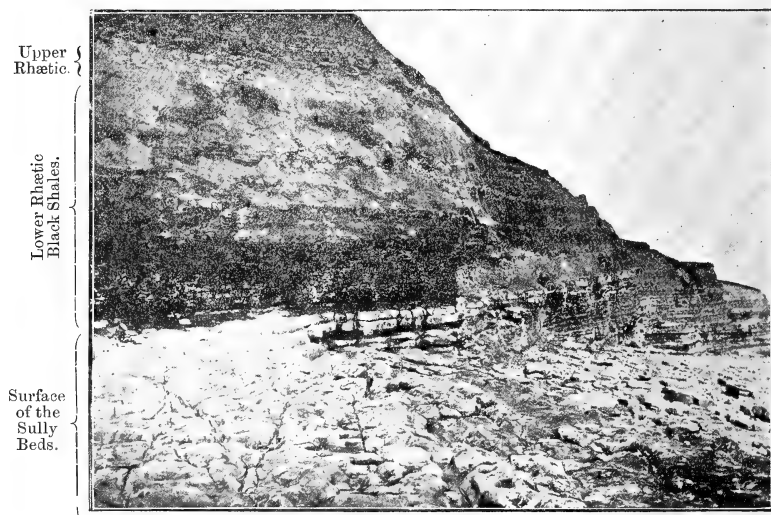
The uppermost marlstone of the Sully Beds is conspicuously waterworn, some of the irregularities projecting at least 5 inches

<sup>1</sup> R. Etheridge, Trans. Cardiff Nat. Soc. vol. iii (1870-71) pt. ii, p. 39  
H. W. Bristow, (Geol. Surv.) Vert. Sect. Sheet 47.

<sup>2</sup> Trans. Cardiff Nat. Soc. vol. xxvi (1893-94) pp. 105-106 & pl.

<sup>3</sup> [Since this paper was written I have made a detailed examination of the Watchet district; and it appears desirable to state here that organic remains are numerous in that district, in marlstones corresponding to these Sully Beds.—June 16th, 1905.]

Fig. 1.—View showing the upper surface of the Sully Beds and the Black Shales, Lavernock Point.



J. Storrie fotogr.

Fig. 2.—View showing the White Lias and its junction with the Lower Lias at Lavernock Point.



J. Storrie fotogr.

above the average level (see fig. 1). Frequently a black-shale deposit is found filling-in these irregularities; but it is occasionally replaced by a soft yellowish-green marl, which passes up gradually into a blackish marl. At that part of the cliff where these notes were made, a layer of grey argillaceous nodules, with quartz-pebbles and fish-remains, rested upon the above-mentioned marl or shale. Doubtless this band of nodules is intimately connected with the 'fish-bed' for which the locality is celebrated. The fact that black shale is intercalated between the 'fish-bed' and Sully Beds in places, is commented upon by Mr. F. T. Howard, F.G.S., who, like most observers, had regarded the 'fish-bed' as the lowest Rhætic deposit in the Cardiff district.

'I was therefore,' he wrote, 'surprised, on removing a block of the conglomerate ['fish-bed'] from its natural position on the foreshore opposite Lavernock Point, to see beneath it and lying directly on a worn surface of Tea-Green Marls, a thin band of black shale, not more than  $\frac{1}{4}$  inch thick, containing numerous crushed specimens of typical Rhætic shells—*Cardium rhæticum*, *Avicula contorta*, and *Pecten valoniensis*. Others may have been represented, but were badly preserved. The band of shale was very irregular. . . .'<sup>1</sup>

There are places where the 'fish-bed' rests directly upon the marlstone of the Sully Beds. As noticed by John Storrrie, the 'fish-bed' is not continuous, but occurs in patches, and the best of these will be found protected by seaweed between low- and high-tide marks:—

'The patches in which it occurs vary from the size of a sixpence to pieces 5 or 6 yards square, and at some places are comparatively close together—at others a considerable distance apart. The bed may be best described as a conglomerate of pure white quartz-pebbles, from the size of a hen's egg downward, all waterworn, and mostly crusted with a greenish-copper tinge, jasper-like pebbles, and also some waterworn pieces of limestone (unfossiliferous, but probably Silurian, from their general texture).'<sup>2</sup>

I am inclined to agree with Mr. Howard that the last-mentioned pebbles are more likely to be of marlstone derived from the Sully Beds. A fine piece of this 'fish-bed,' not altogether of the usual lithic structure, since the greater mass of it consisted of quartz-sand cemented together mainly by carbonate of lime, contained in great abundance the teeth of *Acrodus minimus*, *Gyrolepis Alberti* (?), *Saurichthys acuminatus*, *Sargodon tomicus*, and *Lepidotus* (?),<sup>3</sup> and less commonly of *Hybodus minor* and *H. cloacinus*. Rich as this deposit is in vertebrate-remains, it has not been regarded by our chief authorities as the Bone-Bed. It may be suggested that this basal bone-bed at Lavernock is the equivalent of a deposit of a

<sup>1</sup> Trans. Cardiff Nat. Soc. vol. xxix (1896-97) p. 66.

<sup>2</sup> *Ibid.* vol. xiv (1882-83) p. 100.

<sup>3</sup> The teeth thus denominated are those described by Agassiz as *Sphærodus minimus*, and by Meyer & Plieninger as *Psanmodus orbicularis*. They may belong to the same animal (*Sargodon tomicus*) as the chisel-shaped teeth, but at present it appears desirable to keep the records separate. Charles Moore thought that the knob-like teeth probably belonged to *Lepidotus*, and such teeth are recorded in this paper as '*Sargodon tomicus*' (*Lepidotus*?). See Quart. Journ. Geol. Soc. vol. xvii (1861) p. 499, footnote.

similar nature at Garden Cliff, Westbury-on-Severn. At Garden Cliff, 16 inches above the basal bone-bed is the 'Lower *Pullastra*-Sandstone.' At Lavernock, 18 inches above the presumed equivalent deposit, is a thin layer composed of hundreds of teeth of *Acrodus minimus* and scales of *Gyrolepis Alberti*. At Garden Cliff a deposit of shale, 2 feet thick, separates the Lower from the Upper *Pullastra*-Sandstone; at Lavernock the deposit intervening between the beds that may be regarded as the equivalents of the sandstones measures only 13 inches. Bed 17 is also a 'bone-bed,' and frequently contains vertebræ of *Plesiosaurus*. Black shales with a grey limestone-band separate this bed from a series of sandstone-layers with shale-partings, and frequently full of fish-remains, usually comminuted. If the correlation of the Rhætic deposits (20 to 16) enumerated above be correct, then the next bed in ascending order should be the equivalent of the Bone-Bed (15) of Garden Cliff. This was thought to be the case by Etheridge, and it certainly seems probable. John Storrie wrote:—

'The bone-bed proper . . . is a continuous bed through the whole [Penarth-Lavernock] section, and is described by Etheridge as "a dark-grey grit, or hard indurated pyritic limestone, 2 or 3 inches thick (oftener about 1 inch), made up of minutely-comminuted fragments of fish-teeth, scales, and bones." This bed . . . is accessible in the whole Penarth section, and is always constant in character, except at Lavernock, where it is more pyritized than elsewhere. This bed very rarely contains large bones or spines; on one occasion only have I found such.'<sup>1</sup>

The most persistent strata in the *Pteria* (*Avicula*)-*contorta* Zone are the *Pecten*-Beds (7 & 5 b), especially the lower of the two. At Lavernock, they can be easily traced across the foreshore. Bristow observed that the lower bed was full of *Pecten* (*Chlamys*) *valoniensis*; but, according to my investigations, it was of rather rare occurrence in the actual limestone, and in neither of the *Pecten*-Beds did I find lamellibranchs to be abundant, as is usually the case. However, the Black Shales, for 2 or 3 inches below Bed 5 b, are extremely fossiliferous, containing *Pecten* (*Chlamys*) *valoniensis*, *Pteria* (*Avicula*) *contorta*,<sup>2</sup> scales of *Gyrolepis Alberti*, and coprolites (of fishes chiefly). In places immediately below this shale is a thin earthy limestone-layer with a layer of 'beef' on the under surface. At 5 inches below 5 b is a seam full of *Pteria* (*Avicula*) *contorta*; and in the shales below that again, numerous examples of *Pecten* (*Chlamys*) *valoniensis*, and *Schizodus Ewaldi*, *Gervillia præcursor*, *Protocardium Philippi-anum*, *Orbiculoidea Townshendi*, *Pleuromya* (?), *Placunopsis alpina* (small and large forms), scales of *Gyrolepis Alberti*, teeth of *Acrodus minimus* (rare) and *Saurichthys acuminatus*, and coprolites. The vertebrate-remains occur mostly in a thin layer at 8 inches below 5 b. This is certainly the most fossiliferous horizon in the Rhætic at this locality; and fortunately the deposit is easy to investigate. Black

<sup>1</sup> Trans. Cardiff Nat. Soc. vol. xiv (1882-83) p. 100.

<sup>2</sup> *Pteria*, Scopoli, = *Avicula*, Brug. I am at present engaged in the revision of the representatives of the Pteriidæ from the Rhætic, Liassic, and Inferior-Oolite rocks; and also those of the Mytilidæ from the same rocks.

[To face p. 392.

## SECTION AT LAVERNO

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(Sowerby).

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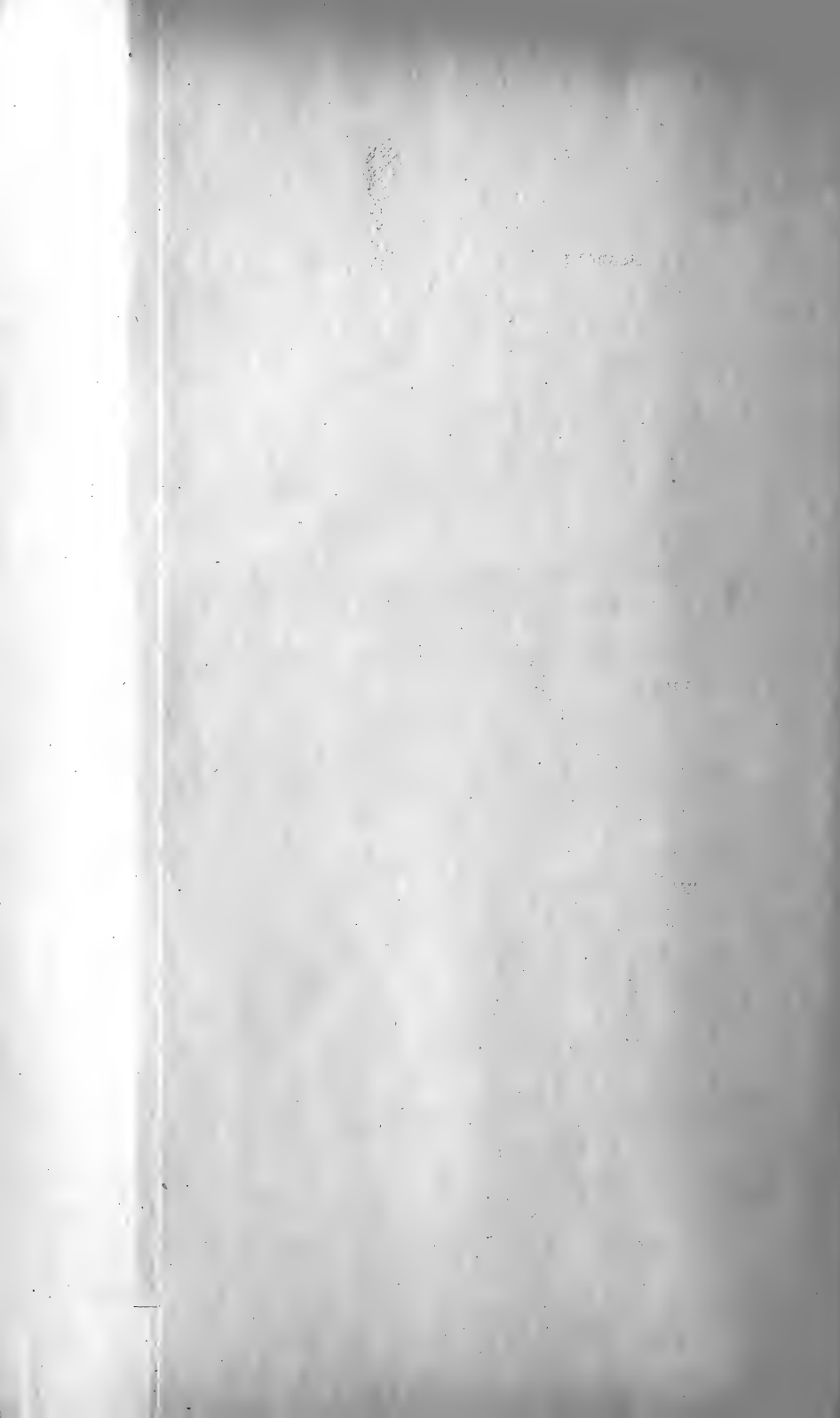
marl.





SECTION AT LAVERNOCK, NEAR CARDIFF.

		Thickness in feet inches.	
HEMERA ROTIFORMIS(?) Limestone-beds and clay-partings: estimated at.		25	0
HEMERA MARMOREA. Marly clays and nodular limestones: about		40	0
LOWER LIAS.	1. Limestone	0	2
	2. Shale	0	3
	3. Limestone, nodular	0	6
	4. Shale, with three beds of rather nodular limestone	1	8
	5. Limestone, nodular: 0 to 2 inches	0	1
	6. Shale, with three beds of limestone	2	6
	7. Limestone, massive: 4 to 8 inches	0	6
	8. Shale	0	6
	9. Limestone: 3 to 5 inches	0	4
	10. Shale	0	3
	11. Limestone	0	4
	12. Shale	0	7
	13. Limestone, fissile	0	3
	14. Shale	1	10
	15. Limestone, massive, with large nodules below; and beneath these are shales, with numerous specimens of <i>Ostrea</i> at the base	2	7
	16. Limestone, massive	0	7
	17. Shale-parting, indistinct in places, forming almost a limestone at the base	0	1
	18. Limestone, nodular	0	4
	19. Shale	0	2
	20. Limestones, five beds, interstratified with shale	4	2
	21. Shale, hard, imperfectly laminated	1	10
	22. Limestone, very much mottled in places, forming almost a limestone at the base	0	7
	23. Limestone, massive	0	7
	24. Shale-parting often indistinct, Bed 41 often adhering to 46	0	1
	25. Limestone, somewhat nodular	0	4
	26. Shale	0	3
	27. Limestone, hard	0	8
	28. Shales, with hard nodules	1	0
	29. Limestone, massive, very irregular surface, sometimes with nodules adhering to it	0	9
	30. Shale	1	1
	31. Limestone	0	4
	32. Shale: 3 to 5 inches	0	2
	33. Limestone	0	5
	34. Shale: 2 inches	0	1
	35. Limestone, nodular, impervious: 2 inches	0	11
	36. Shale: 7 inches	0	6
	37. Limestone, somewhat nodular	0	6
	38. Shale	0	2
	39. Limestone, nodular, impervious	0	3
	40. Shale	0	1
	41. Limestone	0	6
	42. Shale, bluish	1	5
	43. Limestone, in two massive beds, but sometimes conjoined	0	10
	44. Shale, bluish, with one or two layers of impure limestone	1	0
	45. Limestone	0	2
	46. Shale-parting	0	4
	47. Limestone	0	4
	48. Shale or limestone	0	3
	49. Limestone	0	4
	50. Shale or limestone	0	3
WHITE LIAS.*	51. Limestone, five beds, with 1 departing	2	0
	52. Shale	0	4
	53. Limestone	0	2
	54. Shale-parting	0	0
	55. Limestone	0	2
	56. Shale	0	4
	57. Limestone	0	6
	58. Shale, dark, thinly laminated	0	8
	59. Shale and thin limestone	1	1
	60. Limestone, hard	0	6
UPPER RHÆTIC.	61. Shale, hard, thinly laminated	0	7
	62. Limestone, in places giving way for a tough shale	1	0
	63. Paper-shales, hard, brown	1	0
	64. Shales, white or pale-grey, marly, imperfectly laminated, with harder bands in places	6	1
	65. Limestone, hard, grey, weathering into two beds, the upper one being probably the representative of the Sun-Bed	0	1
	66. Shale-parting: indistinct	0	1
	67. Limestone, hard, grey: half an inch to 2 inches	0	0
	68. Shale, grey, parting	0	0
	69. Limestone, greyish-green	0	2
	70. Shale, dark grey	0	1
LOWER RHÆTIC.	71. Limestone, greyish-green: 2 to 4 inches	0	1
	72. Shale, hard, dark grey, with yellow gritty, ripple-marked layers	0	5
	73. Limestone, very gritty, ripple-marked	0	2
	74. Shale, dark grey, with thin gritty, ripple-marked layers	0	7
	75. Limestone, impure, gritty, ripple-marked: 3 to 6 inches	0	1
	76. Shales, black, somewhat thinly laminated	2	0
	77. Shales, black, tough, throwing off a water	1	1
	78. Limestone, grey, micaceous, atomaceous, and occasionally replaced by a more shaly deposit with many <i>Schisti</i> (?) The lower portion is often very pyritic and shaly bed nature	0	0
	79. Hard limestone, slightly pyritic: 1 to 2 inches	0	1
	80. Shale-parting	0	1
SALLY BEDS.	81. Two beds of sandstone with shale parting and 'beef' in between	0	4
	82. Shales, black, laminated	0	1
	83. Limestone, dark grey, slightly pyritic	0	1
	84. Shales, black	0	0
	85. Thin 'bone-bed', interstratified: 0 to 1 inches	0	0
	86. Shales, black	1	1
	87. Thin 'bone-bed'	0	1
	88. Shales, black, laminated	1	6
	89. 'Fish-bed', some times resting directly upon the top stratum of the Sally Beds, and at others separated from them by black shale or marl	0	5
	90. Two somewhat massive beds of hard greyish-blue limestone, weathering yellowish. Upper surface extremely irregular	1	4
I. 'TEA-GREEN MARLS.' (39 feet 4 inches.)	91. Series of blackish-blue marls, with harder zones, passing gradually upwards into harder irregular limestones	6	6
	92. Series of bluish limestones, with dark marly partings. The middle and most massive bed is conglomerate, and can be traced across the foreshore	2	2
	93. Series of blackish-blue and yellowish marls, with hard zones, two of which are near the surface	4	0
	94. Marlstone, rather broken up, yellowish-grey, thin layer of gypsum on the top	0	9
	95. Green marl, much broken up, and containing near the top an irregular zone of gypsum	1	4
	96. Marlstone, greyish-yellow	0	0
	97. Green marl, grey zone in at the top	2	4
	98. Marlstone, hard, greyish-yellow, one of the most conspicuous beds in the section	0	6
	99. Greenish marl	1	4
	100. Marlstone, laminated at the top	1	1
II. RED MARLS.	101. Greenish-grey marls, with hard zone near the centre	2	5
	102. Marlstone, earthy, with gypsum in cavities	1	3
	103. Greenish-grey marls	2	4
	104. Series of five beds of reddish marlstone, parted by thin, green, and less compact layers of marl. Some of the beds are not altogether red	4	2
	105. Greenish marl	0	6
	106. Thin impersistent band of marlstone	0	2
	107. Greenish marl	0	0
	108. Marlstone	0	5
	109. Greenish marl, somewhat laminated in places, compact at the base where it fits into	0	6
	110. Deposit of gypsum, pink	0	9



shales complete the Lower Rhætic Stage, and pass up gradually into a greyish-green marl.

This marl-deposit was much fissured, previous to the deposition of the superincumbent gritty limestone. Into these fissures gritty material was washed. We have here a non-sequence caused by a slight upheaval; and, as a result, certain beds which are found elsewhere, are not to be seen at Lavernock. The beds that are missing at Lavernock measure at Garden Cliff about  $13\frac{1}{2}$  feet. Gradual subsidence, again, in the Lavernock area allowed of the formation of the White Lias (fig. 2, p. 390). At Penarth, Etheridge failed to discover '*Ostrea intus-striata*, so common in Somersetshire and Warwickshire';<sup>1</sup> but at Lavernock it is not uncommon, and is very abundant at Coldknapp, Barry. The probable equivalent of the Sun-Bed completes the series of limestone-beds; and it is of this stratum that I found bored pieces (crypts of *Lithophagus*), on the beach at Seven Sisters' Bay. The specimens of *Ostrea liassica* (two) from this stratum were on the upper surface. The light-coloured shales above the White-Lias limestones are grouped with the White Lias; they contain *Ostrea liassica* abundantly in the lower portion. These are capped by the Paper-Shales, concerning which there has been some debate as to whether they should be classed with the Rhætic or with the Lias.<sup>2</sup> I think that there is little doubt but that they should be grouped with the Lias.

The deposit between these shaly beds and the Lavernock Shales requires no particular comment; but there has been some doubt as to the exact age of the last-named. However, as surmised by Mr. H. B. Woodward, they belong to the *angulata*-zone, having been laid down during the hemera *marmorea*. *Cardinia ovalis* (Stutchbury) did not exist after this hemera. In the Lavernock Shales it is abundant at certain horizons, both at Lavernock and at Leckwithbridge, near Cardiff. At the latter locality *Schlotheimia angulata* (Schlotheim) and *Cardinia ovalis* occur in association; consequently there can be no doubt as to the date of the beds. As the Lavernock Shales are difficult to examine minutely at the typical locality, the section at Leckwithbridge is appended:—

*Thickness in feet inches.*

Limestone, two beds mixed with marly clay .....	about	0	8	
Clay, marly, blue and yellow ...		0	8	
Limestone .....		0	2	
Clay, marly: 4 to 6 inches .....		0	5	
Limestone .....		0	3	{ <i>Ostrea irregularis</i> , <i>Lima</i> ( <i>Plagiostoma</i> ) aff. <i>gigantea</i> .
Clay and limestone-bands .....	1	10		
Limestone, dark grey .....	0	3		
Clay, hard, marly, reddish blotches	0	5		

<sup>1</sup> Trans. Cardiff Nat. Soc. vol. iii (1870-71) pt. ii, p. 50.

<sup>2</sup> H. B. Woodward, 'The Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iii (1893) p. 119.

[Leckwithbridge Section (*continued*).]

		Thickness in feet inches.		
LAVERNOCK SHALES.	Limestone .....	0	4	<i>Ostrea irregularis</i> .
	Clay, with three bands of limestone, totalling 7 inches .....	4	0	{ <i>Ostrea irregularis</i> , <i>Lima gigantea</i> , <i>Cardinia ovalis</i> , <i>Schlotheimia angulata</i> (Schloth.).
	Limestone .....	0	3	
	Clay and limestones .....	12	0	
	Clay, blue; <i>Cardinia ovalis</i> abundant .....	3	0	
	Clay and limestones. Some of the limestone-bands become nodular .....	22	4	
				<i>Cardinia ovalis</i> (Stutchbury); <i>Ostrea irregularis</i> , Münster; <i>Lima gigantea</i> (Sowerby); <i>Pholadomya fortunata</i> , Dumortier; <i>Littorina</i> cf. <i>minuta</i> , Terq. & Piette; ossicles of <i>Pentacrinus</i> , radioles of <i>Cidaris</i> ; <i>Rhynchonella</i> aff. <i>calcicosta</i> , Dav.; <i>Dentalium etalense</i> , Terq. & Piette.

Concerning the higher beds at Lavernock no details can be given; they are inaccessible, but limestones predominate. Proceeding farther westward along the coast, the other side of the syncline is entered upon, and the strata are soon passed over in descending order, until at St. Mary's-Well Bay, Sully, the Rhætic reappears.

## (B) St. Mary's-Well Bay, Sully.

At this locality the whole of the Rhætic Series can be studied; but, since the Lavernock section has been dealt with in such detail, it will be sufficient for our present purpose to describe the basal portion only of the exposure. The beds are very much disturbed, owing to a fault—that which starts at Dinas Powis. The result is that the Rhætic Beds are faulted against the littoral Keuper, and in the downward course that portion of the series which I have denominated the Sully Beds has been prettily contorted.

The Bone-Bed seen in this section, although consisting of several layers, as at Lavernock, is nevertheless lithically distinct. The main band is a hard grey limestone, seldom pyritic, but usually crowded with fish-remains, although no quartz-pebbles were observed. Below the Bone-Bed are black shales with intermittent hard layers, as noticed in the appended section:—

## Thickness in feet inches.

15. A series of sandstone- and limestone-layers, with partings of shale.....	1	0	{ <i>Gyrolepis Alberti</i> (teeth ? & scales); a lamellibranch ( <i>Schizodus</i> or <i>Pullastra</i> ) not uncommon
16. Shales, black.....	1	5	
17. Limestone; intermittent.....	0	1	
18. Shales, black.....	0	5	
19. Limestone, earthy; intermittent	0	1	
20. Shales, black.....	1	4	
21. Rust-coloured layer.....	0	0½	<i>Gyrolepis Alberti</i> (rare).

Thickness in feet inches.

SULLY BEDS.	{	Marlstone, hard, greenish-grey, massive at the top, but nodular and mixed with black and yellow marl below .....	4	6	{	<i>Ostrea Bristovi</i> (very com- mon); <i>Pteria (Avicula)</i> <i>contorta</i> (abundant in a thin layer at the top); <i>Sargodon</i> (?), <sup>1</sup> <i>Lepidotus</i> (?); <i>Modiola</i> .
		Marls and marlstones.....				

Large masses of marlstone from the Sully Beds, scattered about on the beach, are crowded with *Ostrea Bristovi*, Etheridge, MS. (see p. 422), and the beds also frequently contain traces of the mineral baryto-celestine. These strata do not appear to have attracted any attention; they must have been observed, because Mr. E. T. Newton, F.R.S., informed me that an *Ostrea*, similar to that which I had submitted to him for examination from this locality, was preserved in the Museum of Practical Geology, Jermyn Street, and bore the legend '*Ostrea Bristovi*, Etheridge, MS. From near Penarth.' In a thin layer at the top of the Sully Beds, *Pteria (Avicula) contorta* is very abundant.<sup>2</sup> Their fossil contents render it incumbent that these beds should be classed with the Rhætic, but an arbitrary line of division must be drawn between them and the 'Tea-Green Marls,' which will be subject to alteration according to the records of fossils.

#### (C) Cross Farm, near Dinas Powis.

In the memoir descriptive of the geology of the Cardiff district it is observed that

'To the west of the Lower Penarth or Lavernock outlier there is a considerable tract just high enough to take in some of the Rhætic shales and limestones, but nowhere high enough to touch the Lias.'<sup>3</sup>

Since the district was geologically surveyed between the years 1892

<sup>1</sup> Concerning this specimen, Dr. A. Smith Woodward, F.R.S., wrote (*in litt.*):—'Premaxilla with cutting-teeth. Might be *Sargodon*, or perhaps a Pycnodont fish.' It is preserved in the collection of Mr. E. Talbot Paris.

<sup>2</sup> The abundance of *Pteria contorta* in the uppermost layer of the Sully Beds here, and the record by Mr. F. T. Howard, F.G.S., of 'numerous crushed specimens of typical Rhætic shells—*Cardium rhæticum*, *Avicula contorta*, and *Pecten valoniensis*'—in a thin layer of shale below the 'fish-bed,' Trans. Cardiff Nat. Soc. vol. xxix (1896–97) p. 66, is interesting in connection with a statement made by Prof. S. H. Reynolds & Dr. A. Vaughan in a footnote to their admirable paper on 'The Rhætic Beds of the South-Wales Direct Line' Quart. Journ. Geol. Soc. vol. lx (1904) p. 200. In that footnote they remarked:—'We have ventured to dissent somewhat from Mr. Richardson's correlation of the beds at Garden Cliff. Seeing that *Avicula contorta* and *Schizodus* occur plentifully below his Bone-Bed (Bed 15), it does not appear to us that this bed can be considered to be on the same horizon as that at Sodbury, which is well below the level at which these mollusca commence to occur in any abundance.' As to whether the Sodbury Bone-Bed was on the same horizon as that numbered 15 at Garden Cliff was a question for them to decide, and the evidence which led to their answer in the negative is quoted above. In view of the details obtained in Glamorganshire (and also in the Watchet district), this hardly seems conclusive.

<sup>3</sup> 'The Geology of the South-Wales Coalfield: Pt. iii' Mem. Geol. Surv. 1902, p. 63.

and 1896, a large quarry has been opened out in the Lower Liassic limestones of this outlier, near Cross Farm, and the junction of these beds with the White Lias (A of Lavernock) exposed to view. The section is as follows:—

		Thickness in feet inches.		
LOWER LIAS.	Marl and limestone-fragments .....	seen	0 10	
	Three bands of limestone, with marly partings .....	2	10	{ <i>Ostrea liassica</i> and radioles of <i>Pseudo-diadema</i> .
	Limestone .....	0	7	
	Limestones and shales .....	5	2	
	Shale .....	0	8	{ <i>Ostrea liassica</i> common.
	Limestone in two conspicuous beds .....	0	8	
	Shale .....	0	4	
	Limestone .....	0	5	
	Limestone and shales .....	9	5	
	Three beds of limestone, with very thin partings of shale. Locally called 'the Washers' .....	0	7	<i>Ostrea liassica</i> .
	Clay .....	0	1	
	Limestone .....	0	6	<i>Ostrea liassica</i> .
	Shale, thinly laminated in the upper portion, clayey in the lower .....	0	6	
	Limestone, blue-centred .....	0	3	
	Paper-Shales, as at Lavernock .....	1	0	
WHITE LIAS.	Shales, bluish, marly .....	seen	3 6	

Unfortunately, the sequence downwards cannot be ascertained; but in the lane-side near the buildings at Cross Farm the following details may be observed:—

		Thickness in feet inches.		
	Shales, black, with soft gritty layers at the base .....	seen	3 0	{ In the limestone <i>Pullastra arenicola</i> is abundant: wood and fragments of fish-scales occur. In the quartz-sand <i>Acrodus minimus</i> , <i>Saurichthys acuminatus</i> , and <i>Gyrolepis Alberti</i> are common.
	15. Limestone, hard, grey, micaceous, with quartz-sand immediately below .....	0	5	
	16. Shales, black .....	0	4	
	17. Sandy layer, chocolate-coloured ...	0	1	<i>Gyrolepis Alberti</i> .
		[Gap]		
SULLY BEDS.	Marlstone, hard, greenish-grey: 4 to 15 inches .....	0	9	<i>Ostrea Bristovi</i> .
	Marly shales, dark greenish-grey and brown, with sandy seams .....	2	0	
	Marlstone, hard, greenish-grey .....	0	11	<i>Ostrea Bristovi</i> .

The lamellibranchs in Bed 15 are, on the whole, well-preserved and extremely abundant. As I did not recognize the fossil, I submitted specimens to Mr. E. T. Newton, who replied:—'This is the shell which is known as *Pullastra arenicola*, Strickland.' *Ostrea Bristovi* abounds in the Sully Beds at this locality; but, in a deep wheel-track some 350 yards to the north-east, the equivalent beds

are found to have changed, both as regards faunal and lithic characters :—

		Thickness in feet inches.		
SULLY BEDS.	Shales, black, clayey .....	seen	2    0	
	a. Limestone and quartz-sand .....	0    4		<i>Gyrolepis Alberti</i> ; <i>Ostrea</i> (?)
	b. Limestone, earthy .....	0    3		
	c. Clay .....	0    1		
	d. Limestone, irregular masses: 0 to 9 inches.....	0    5		<i>Gyrolepis Alberti</i> .
	e. Marl, black and brown .....	0    6		
	f. Limestone, hard, crystalline in the upper portion: the lower simulates Carboniferous Limestone .....	0    7		Fishes (scales and teeth).
	g. Marl, hard, shaly .....	seen	0    10	

In a road-cutting between Merch and Cogan Hall certain Rhætic beds are exposed, including a bone-bed :—

		Thickness in feet inches.		
10 to 14 ?	Shale, black, clayey: possibly about	4    5		[ <i>lepis</i> .
15.	Limestone, hard, grey: 0 to 2 inches	0    1		<i>Schizodus</i> (?) ; <i>Gyro-</i>
16.	Shale, black, clayey .....	0    6		{ <i>Saurichthys acuminata</i> , <i>Gyrolepis Alber-</i>
17.	Arenaceous rust-coloured deposit ...	0    1		<i>ti</i> ; quartz-pebbles.
18 to 21.	Shale, black .....	estimated at	3    0	

It is impossible to correlate these beds with certainty, and so the numbers affixed to them must be regarded merely as suggestive.

About halfway between the foregoing section and the place where this lane joins the Cogan road, fish-remains are not uncommon in the Sully Marls. Although these beds are well-developed in this outlier, it is recorded in the Geological-Survey Memoir that, whereas a certain zone occurs 26½ feet below the Rhætic Black Shales at Lavernock, in this outlier it occurs only 14 feet below that datum-level.<sup>1</sup> This may point to some overlap of the Sully Beds (see p. 413).

## ii. Barry to Cowbridge.

In the district between Barry and Cowbridge there are three important sections of the beds under consideration, namely, at Barry (Coldknap), Cadoxton, and Tregyff (near Cowbridge).

Two small outliers of Rhætic Beds occur on Barry Island. The northernmost patch has been investigated by Mr. F. T. Howard, F.G.S., who has recorded a number of fossils.<sup>2</sup>

### (A) Coldknap, Barry.

In the low cliff near Coldknap Farm, and facing Barry Island, is a section of much interest and importance. In the Geological-Survey Memoir on the Cardiff district it is recorded that

'Rhætic shales are exposed again as an inlier near Coldknap. They form a

<sup>1</sup> 'The Geology of the South-Wales Coalfield: Pt. iii.—The Geology of the Country around Cardiff' Mem. Geol. Surv. 1902, p. 54.

<sup>2</sup> Trans. Cardiff Nat. Soc. vol. xxvii (1894-95) p. 42.

small anticline running rather south of east, and are traversed by several small faults, all probably branches from the Coldknapp Fault.'

A sketch-section is given by Mr. Strahan (*op. cit.* p. 64). Beneath the *Ostrea*-limestones are the following beds:—

Thickness in feet inches.

Paper-Shales.

WHITE LIAS.	A.	Marl, bluish-grey, with harder bands	5	6	<i>Modiola minima</i> , Moore
		Calcite-layer	0	0½	[non Sowerby.
		Band of indurated marl	0	2½	
		Marl, bluish-grey	0	2	
	B.	Layer composed of the valves of an <i>Ostrea</i>	0	2	<i>Ostrea</i> sp.
		Marl, bluish-grey	2	10	
		Limestone in two beds, bluish-grey weathering yellow. The lower bed in particular resembles the Sun-Bed, and exhibits a conchoidal fracture	0	6	
	C.	1. Shales, bluish-grey, calcareous.	0	5	
		2. Rubbly limestone, with more compact limestone immediately below, weathering yellowish. Fossils most abundant in the upper portion	0	5	<i>Plicatula intus-striata</i> , <i>Pl. hettangiensis</i> , and <i>Lima</i> ( <i>Plagiostoma</i> ) <i>valoniensis</i> , common; <i>Protocardium Philipianum</i> , <i>Pleurophorus</i> (?), <i>Modiola minima</i> (?) (large) Moore, <i>Ostrea</i> sp.; an ostracod.
		3. Shale	0	2	<i>Pleurophorus</i> (?) & <i>Protocardium</i> (?) as casts, <i>Plicatula intus-striata</i> .
		4. Limestone, yellowish	0	1½	<i>Lima</i> ( <i>Plagiostoma</i> ) <i>valoniensis</i> .
		5. Shale, blue and yellow, indurated	0	9	Shell-débris; <i>Plicatula intus-striata</i> .
		6. Gritty layer	0	2	
		7. Shale, greenish-grey, thinly laminated	0	2	
		8. Limestone, blue-centred	0	3	
		9. Shale, greenish-grey ... about	0	3	
		10. Grit, pyritic, ripple-marked: 0 to 3 inches.	0	2	

UPPER RHÆTIC. 4. Shales, greenish-grey.

The White-Lias Beds (C) in the foregoing section are extremely fossiliferous, and it is remarkable that they have not attracted attention on this account. The strata between the Paper-Shales and the Upper Rhætic marl or shales (4) at Lavernock measure 8 feet 10¼ inches, and at Barry 12 feet 3½ inches, the increase in thickness at the latter locality amounting therefore to close upon 3 feet 6 inches.

Mr. H. B. Woodward has observed a bone-bed in crevices of the top-bed of marl, at the base of the Black Shales at Cadoxton.<sup>1</sup>

<sup>1</sup> Proc. Geol. Assoc. vol. x (1888) p. 531.



The most interesting exposure in this neighbourhood is in the sides of a field-road, near the brook, about three-fifths of a mile in a direction a little to the south of west of Cadoxton Church.

## (B) Cadoxton.

Thickness in feet inches.

SULLY BEDS.	a. Marls, yellow and black .....								
	b. Limestone, hard, dark, in masses mixed with dark brown clay : 3 to 9 inches .....	0	6						
	c. Shales, black, earthy .....	1	8						
	d. Limestone, hard, dark .....	0	6						
	e. Shales, black and brown, with yellow streaks.								

(*Lepidotus* (?), *Acroodus minimus*, *Gyrolepis Alberti*; bone (*Labyrinthodon* ?); *Ostrea Bristovi* (see Pl. XXXIII, fig. 4), *Pteria* (*Avicula*) (?), *contorta*; *Natica* (?), *Ostrea Bristovi* (rare).

The necessity for grouping the Sully Beds with the Rhætic will be obvious from the foregoing section, although it should be mentioned that the fossils are not individually numerous. Here it will be noticed that *Ostrea Bristovi* is associated with *Pteria* (*Avicula*) *contorta* and other Rhætic lamellibranchs.

*Pteria* (*Avicula*) *-contorta* Black Shales, with an extremely fossiliferous *Pecten*-Bed, are to be seen in the deeply-cut lane three-fourths of a mile north by east of Cadoxton Church: the limestone-bed yields *Pecten valoniensis*, *Pteria* (*Avicula*) *contorta*, *Schizodus Ewaldi*, and a *Placunopsis* similar to that which occurs in Bed I of the Redland (Bristol) section.<sup>1</sup>

Between the last section and Redland (near Bonvilston) the Rhætic deposits are but seldom exposed. Black shales with thin *Pecten*-Limestones have been observed in a brook on the north side of Bears Wood, south of Wenvoe Castle, and again west of St. Nicholas, 'on both sides of the valley and in Coed-y-Cwm.'<sup>2</sup>

In a road-section at Redland (Sheets 261, 262) some interesting details can be observed. In the Geological-Survey Memoir on the country around Bridgend is the following passage:—

'A small quarry 100 yards south of Redland shows the *Avicula-contorta* Shales overlying a hard yellow dolomitic rock of Tea-Green Marl age, while Carboniferous Limestone, apparently in place, crops out on the opposite side of the road. Here, then, we can fix a point on the Keuper coast-line, for the limestone-ground to the north was still above water at the close of the Keuper-Marl period.' ('Geology of the South-Wales Coalfield: Pt. vi' 1904, p. 30.)

In August 1904, the section on the west side of the road exposed a boss of Carboniferous Limestone wrapped round by Black Shales. This boss, at the road-level, measured  $2\frac{1}{2}$  feet across, and stood 2 feet high. A little farther in the direction of Blackland the Black

<sup>1</sup> A. Rendle Short, Quart. Journ. Geol. Soc. vol. lx (1904) p. 171.

<sup>2</sup> 'The Geology of the South-Wales Coalfield: Pt. iii' Mem. Geol. Surv. 1902, p. 65.

Shales were more in evidence, and pieces of a *Pecten*-Limestone containing the characteristic lamellibranch, fragments of a *Placunopsis*, and fish-scales, were lying about. Still nearer Blackland higher beds were exposed, including thin bands of pale limestone intercalated in similarly-coloured shale, altogether 3 feet 4 inches thick, and resting upon grey and yellow shale (belonging presumably to the Upper Rhætic), of which a thickness of 6 inches was visible. Where the *a* in Redland comes on the 1-inch Geological-Survey map there is a large quarry in the Carboniferous Limestone. In one place some green marl has been washed down a fissure, but on the whole, as noticed by Mr. Cantrill,

the Rhætic soil can be recognized so close to the brow of a large quarry in Carboniferous Limestone, as to suggest that the Keuper is here wholly overlapped, as shown on the map.<sup>1</sup>

A pond to the east of the ancient camp at Leige Castle is in the Black Shales, and from pieces of *Pecten*-Limestone were obtained Labyrinthodont-bones (small pieces), scales of *Gyrolepis*, coprolites (fish), and fragments of *Pecten* (*Chlamys*) *valoniensis*. A section showing the junction of the Rhætic and Carboniferous-Limestone deposits can be studied in the roadside 200 yards north-west of Ty'n-y-coed, but here—as at Redland—the Rhætic Beds exhibit no littoral facies, such as might be at first expected.

The finest section in the Cowbridge district is in a road-cutting at Tregyff, near the St. Mary-Church Road Station on the Cowbridge & Aberthaw Railway. It is dealt with in the Geological-Survey Memoir (*op. cit.* p. 40) in the following short passage:—

‘They [the Rhætic deposits] emerge south-east of Wren Castle, and here for the first time exhibit signs of the oncoming of a more arenaceous type, in the intercalation of bands of greenish-grey sandstone. These may be traced southwards along the valley, but are especially well-shown in a road-cutting at Tregyff, though the beds undulate gently down the road westwards at such an angle that only a few feet are exposed. They consist of sandstone with *Protocardium Philippianum* and *Avicula contorta*, blue sandy marls, a thin conglomeratic band containing pebbles of Carboniferous Limestone and chert and black limestone with *Pecten valoniensis*.’

### (C) Tregyff, near Cowbridge.

		Thickness in feet inches.	
Limestone, pieces not <i>in situ</i> .			
Shales, brown (several feet).			
Limestone, dark .....		0	1
Shales, brown .....		1	3
LOWER RHÆTIC.	{	Shales, black, with several bluish gritty layers .....	
		1	6
		Limestone, brown and blue.....	0 1½
		Shale, weathering brown .....	0 6
		Sandstone, fine-grained, calcareous	0 1 Casts of worm-burrows
		5a { Shale, black, weathering brown ...	0 7 [on the underside.

<sup>1</sup> ‘The Geology of the South-Wales Coalfield: Pt. vi.—The Geology of the Country around Bridgend’ Mem. Geol. Surv. 1904, p. 39.

## Thickness in feet inches.

LOWER RHETIC.

	Sandstone, light-grey, fine-grained, calcareous.	0	3	<i>Pteria (Avicula) contorta</i> (two specimens).	
	Shales, black, thinly-laminated, weathering brown, and containing thin gritty layers .....	1	2	{ <i>Pecten (Chlamys) valoniensis</i> , <i>Schizodus Ewaldi</i> ; <i>Acrodus minimus</i> , teeth and scales of <i>Gyrolepis Alberti</i> .	
5b.	Limestone, grey, massive, with muscovite-flakes .....	0	10		
	6. Parting, usually of shale, sometimes impure limestone .....	0	1		
	7. Limestone, grey, massive .....	0	6	{ <i>Pecten (Chlamys) valoniensis</i> , <i>Placunopsis alpina</i> (large).	
	8. Shale, black, weathering brown, thinly laminated, with a few gritty layers .....	0	4	Much shell-débris.	
	9. Limestone, grey, thinning out in places, often arenaceous .....	0	1	{ <i>Pecten (Chlamys) valoniensis</i> , <i>Pteria (Avicula) contorta</i> , coprolite. <i>Acrodus minimus</i> (common), <i>Saurichthys acuminatus</i> , 'Sargodon tomicus' ( <i>Lepidotus</i> ?), ichthyodorulite of <i>Hybodus</i> ; casts of a lamellibranch of <i>Schizodus</i> -type; wood. <sup>1</sup> <i>Schizodus</i> ? (casts).	
10 to 14	{ Shales, black, laminated, with several gritty layers near the top, and at the base, towards the eastern end of the section, a	2	5		
15	{ Massive bed of conglomerate (see p. 402): 0 to 8 inches.....	0	2		
	{ Hard band of grit: 1 to 3 inches .				
	16. Shales, black, with gritty layers containing a few fish-scales (indeterminable) .....	0	9	{ <i>Pteria (Avicula) contorta</i> ; a few fish-scales ( <i>Gyrolepis</i> ?) and coprolites (fish). <i>Hybodus minor</i> (1 tooth), <i>Gyrolepis Alberti</i> (scales, rare); <i>Pteria (Avicula) contorta</i> , <i>Modiola</i> , fragments of lamellibranchs, and carbonaceous matter.	
	17. Limestone, hard, grey, slightly sandy in places, usually in two beds with a little shaly matter intervening between them .....	0	7		
	18. Marl, greenish-grey and bluish, imperfectly laminated. Near the top are little lumps of a hard limestone simulating Carboniferous Limestone.....	1	4		
SULLY BEDS.	{ Limestone, hard, compact, greyish-green, sandy, resembling, from a distance, Carboniferous Limestone: containing occasionally fragments of a white earthy marlstone and small quartz-pebbles .....	0	10		
	{ Marlstone, yellowish-green; visible in the gutter .....				
				{ <i>Acrodus minimus</i> (common), 'Sargodon tomicus' ( <i>Lepidotus</i> ?), fish-scales (fragments common).	

From a lithological standpoint the Tregyff section presents many features of interest. At the base are hard marlstones which are best

<sup>1</sup> All from the Conglomerate-Bed.

grouped with the Sully Beds. The fossils recorded from the limestone-bed were observed mostly in the uppermost portion. Above is a deposit of soft marl, which yielded single examples of *Pteria* (*Avicula*) *contorta*, *Modiola* (indeterminable), and *Hybodus minor* (tooth).

The most interesting stratum in the foregoing section is the Conglomerate-Bed distinguished as 15.

In a series of deposits such as the Rhætic, it is often difficult to correlate with certainty the various component deposits seen at different localities. In certain districts, however, as in North-West Gloucestershire and Worcestershire, the same lithic characters are preserved by a bed over a considerable area; but in Glamorganshire such is not the rule, and as the beds are traced westwards there is increasing evidence of the proximity of land. Here, at Tregyff, the Lower Rhætic was deposited close to a shoreline composed of Carboniferous rocks, and as a result the Secondary rocks became what Charles Moore would have termed 'abnormal.' Therefore, it will be understood that when in the foregoing record, and in those of sections farther west, a bed is distinguished by a certain number, that number suggests rather than implies contemporaneity with a similarly-notated deposit elsewhere.

Mr. E. B. Wethered, F.G.S., has kindly supplied me with the following notes on certain limestone- and chert-pebbles from the Conglomerate-Bed:—

'Limestone-pebble from the Conglomerate-Bed, Tregyff, near Cowbridge.—An impure limestone containing a number of organic remains, but so altered by molecular change that it is very difficult to determine them beyond a few spines, crinoid-ossicles, fragments of polyzoa and mollusca. The main feature of the slide is the presence of a large number of crystals of salt and gypsum, which are apparently of secondary origin.'

'Chert-pebble from the Conglomerate-Bed, Tregyff, near Cowbridge.—Looked at in a hand-specimen this appears to be a chert enclosing oolite-granules. The sections of this chert seen under a microscope show it to contain a number of ovoid bodies, some of which include a nucleus, but the usual form of concentric structure characteristic of oolite-granules is not apparent. Originally the rock was probably a limestone, which has been transformed into chert by the gradual replacement of the carbonate of lime by silica.'

The *Pecten*-Beds (7 & 5b) are well-developed; but the superincumbent deposits are difficult to correlate, both on account of the lack of distinctive fossils and the growth of vegetation, which obscures the upper portion of the section to a large extent.

In the neighbourhood of Ty-ganol the lower portion of the Lower Rhætic consists mainly of a sandstone-deposit. This sandstone is well exposed by the roadside, 180 yards north-east by north of Ty-draw, and therefrom were obtained a specimen of *Hybodus minor* and a few scales of *Gyrolepis Alberti*. The whole of the lower stage, however, is not replaced by an arenaceous deposit, because

Mr. Cantrill has noticed some *Pecten*-Limestones between Ty-ganol and Pentre.

At Pentre certain White-Lias beds have been preserved as an outlier; also a few Rhætic beds, as proved by pieces of *Pecten*-Limestone with fragments of *Pecten* (*Chlamys*) *valoniensis*. This outlier is situated 200 yards east of the road, and owes its preservation to faulting, whereby the beds composing it have been let down on the north against the Carboniferous Limestone. Formerly there was a quarry here, but now the excavation is filled with water. On the south side of this pond the following beds are exposed:—

		Thickness in feet inches.	
WHITE LIAS.	Clay, yellow, shaly at the base: visible .....	1	0
	Limestone, brown and dark-coloured; <i>Plicatula intus-striata</i> common <sup>1</sup> .....	0	5
	Clay .....	0	3
	Limestone .....	0	2
	Clay, yellow .....	0	5
	Limestone; <i>Modiola minima</i> common .....	0	2
	Shales, dark, hard, with thin beds of limestone .....	seen	1 6

The uppermost limestone in the foregoing record exactly resembles the bed bearing a similarity to the Sun-Bed at Barry (p. 398).

The account of these Rhætic beds given by Mr. Cantrill shows that, in the St. Hilary district, few if any exposures escaped his attention. But there are one or two interesting facts not as yet recorded. By the side of a pond, indicated by the arrow on the Geological-Survey Map, and some 300 yards to the west of Garn, is a limestone-bed very much resembling, lithically, a certain development of the *Estheria*-Bed of North-West Gloucestershire. This stratum contains *Pseudomonotis fallax*, and dips gently to the north-east by north: it is, therefore, most probably on the same horizon as the *Pseudomonotis*-Bed.

In the floor of the lane between St. Hilary and St. Hilary Common, there is a quite fossiliferous bone-bed. The deposit is a pale, slightly-arenaceous limestone, containing obscure casts of a lamellibranch (*Schizodus* ?), scales and teeth of *Gyrolepis Alberti*, *Acerodus minimus*, and a few indeterminable fragments of bone.<sup>2</sup>

In the roadside at The Cross, south of St. Hilary, the Rhætic sandstones are exposed. There is, however, a considerable amount of black shaly matter present, and in the sandstone-layers intercalated in this shale—especially in that about an inch thick towards the middle (vertical) of the exposure—‘plant-remains’ are abundant.

<sup>1</sup> A rock crowded with this lamellibranch, but not found *in situ*, is assigned to this horizon, owing to the similarity of lithic structure.

<sup>2</sup> See also Buckland & Conybeare, Trans. Geol. Soc. ser. 2, vol. i (1824) p. 301; and ‘The Geology of the South-Wales Coalfield: Pt. vi—The Geology of the Country around Bridgend’ Mem. Geol. Surv. 1904, p. 41.

Between How Mill and The Herberts a road-section shows sandy beds and shale:—

		Thickness in feet inches.			
RHÆTIC.	a. Shale, black .....				
	b. Sandstone, fine-grained, calcareous: 1 to 2 inches .....	0	1	{	<i>Gyrolepis Alberti</i> , and some other fish- remains, but indeter- minable.
	c. Shale, grey .....	0	5		
	d. Limestone, arenaceous, nodular: 1 to 2 inches .....	0	1		
	e. Shale, black .....	0	1		
	f. Sandstone, hard and dark-grey bands near the base, but otherwise some- what soft.....	6	0	{	In the hard por- tions were noted casts of a lamelli- branch and numerous small pieces of wood.
KEUPER. I. Hard, grey, rocky marls .....					

As no distinctive fossils were obtained from these rocks, it is only possible to say that they belong to the Lower Rhætic.<sup>1</sup>

The sections in the railway-cuttings north and south of St. Mary-Church Road Station have been described in detail in the Geological-Survey Memoir on the district<sup>2</sup>; and, in both cases, below the representative of the Paper-Shales of the Lavernock Section, is the White Lias—shaly and marly matter constituting the greater mass of the deposit. Owing to the ample details recorded in the memoir just cited, it is unnecessary to discuss these sections here; and the same remark applies to the sections of the Rhætic Beds at both ends of the railway-cutting at Cowbridge.<sup>3</sup> That at the southern end is the more satisfactory of the two. The Paper-Shales are 8 inches thick, and the Rhætic and White-Lias deposits between them and the Keuper measure 19 feet.

Having dealt with the sections of the Rhætic deposits in the district between Barry and Cowbridge, I may now direct attention

<sup>1</sup> Higher up, in a field on the south side of the road, there is a quarry in blue-limestones with shale-partings—the upper beds full of *Psiloceras Johnstoni*. They are crowded with gasteropods, the commonest form of which is *Cerithium gratum*, Terquem. In the quarry on the north side of the road, as noticed by Mr. F. T. Howard, Trans. Cardiff Nat. Soc. vol. xxx (1897–98) p. 41, are several limestone-beds crowded with *Thecosmilia* cf. *irregularis*, Duncan. Halfway between Llandough-juxta-Cowbridge and Llanfihangel are two quarries, one on each side of the valley. In that on the north side is a bed full of the same species of *Thecosmilia*, while the other fossils included *Pteria* (*Avicula*) *inæquivalvis*, *Lima valoniensis*, *L. tuberculata*, *Modiola minima* (?), *Pinna*, *Ornithella sarthacensis*, and radioles of an echinoid. The quarry on the opposite side yielded *Psiloceras planorbis*, *Lima gigantea* (small), *Pecten* aff. *calvus*, *Pinna*, *Ostrea*, *Modiola minima*, Sow., and a gasteropod.

<sup>2</sup> 'The Geology of the South-Wales Coalfield: Pt. vi' (1904) pp. 41–44.

<sup>3</sup> *Ibid.* pp. 44–48 and Trans. Cardiff Nat. Soc. vol. xxx (1897–98) pp. 36 et seqq.

to the outliers in the neighbourhood of Pendoylan, at Peterston, and St. Fagans.<sup>1</sup>

In the Pendoylan outlier, Mr. Cantrill discovered pieces of *Pecten*-Limestone at a pond 100 yards south-east of the vicarage; and I found fragments of a similar rock at a pond immediately west of the footpath running from Pendoylan to Ty'n-y-cae, at a point due west of the Tre-sfoch. Mr. Cantrill obtained spines and tubercles of an echinoid (queried as an *Acrosalenia*), from a *Pecten*-limestone thrown out from a well-excavation, 80 yards north-west of Pendoylan School. The fact is interesting, because, except for the records of an echinoid (which may be a species of *Pseudodiadema*) at Coomb Hill near Cheltenham,<sup>2</sup> and at Church Lench (Worcestershire),<sup>3</sup> I am not aware that such remains have been noticed in beds of *contorta*-age.<sup>4</sup> Mr. Cantrill, moreover, observed Rhætic limestone in the soil of a field, at about 150 yards along the footpath running south-eastward from Ty'n-y-cae. Near the hedge at the same spot are shallow excavations, in which fragments of sandstone containing *Acrodus minimus*, and bits of fish-scales, can be seen.

In the Peterston outlier Black Shales and *Pecten*-Limestones have been noticed in a brook between Maendy and Allt-isaf, but the only exposure of any interest is at the village of St. Bride's, in a shallow road-cutting near the church. On the west side a considerable thickness of black shale occurs, together with a bed of sandstone crowded with the teeth of *Acrodus minimus*; while on the east the 'Tea-Green Marls' (Keuper) are visible. There is no evidence of the Sully Beds.

In the sides of a pond about 200 yards west of Pen-hefyd, St. Fagans, Black Shales and a *Pecten*-Limestone (containing *Pecten valoniensis* and fragments of a *Placunopsis*?) are visible. These

<sup>1</sup> The occurrence of Rhætic deposits has been noted by the officers of the Geological Survey at certain localities which have not been touched upon in this paper, because, although I visited these localities, I did not obtain any additional information. The results of the official investigations are chronicled at the following pages of the memoir on 'The Geology of the South-Wales Coalfield: Pt. iii'—p. 66 (St. George's); p. 66 (Coed-y-gof); p. 66 and in Pt. vi (1904) p. 39 (Castell-y-Mynach); p. 65 (Saintwell); and p. 65 (Vishwell).

<sup>2</sup> 'Handbook to the Geology of Cheltenham' 1904, p. 210.

<sup>3</sup> Proc. Cotteswold Nat. F.-C. vol. xv (1904) p. 40.

<sup>4</sup> In that part of the memoir on 'The Geology of the South-Wales Coal-field which deals with the Cardiff district (pt. iii, 1902, p. 56) there is the following passage:—'The fauna includes scarcely any examples of the four great marine orders, Actinozoa being unknown in the *Avicula-contorta* beds, Echinodermata being represented by one form of feather-star, Brachiopoda by one form of *Discina*, Cephalopoda by a *Beloteuthis*, the horizon of which, however, there is reason to doubt.' Later discoveries require this statement to be modified somewhat: in addition to the occurrence of an echinoid in the *Pteria (Avicula)-contorta* Beds, a compound coral has been described by the late R. F. Tomes (Quart. Journ. Geol. Soc. vol. lix, 1903, p. 403); and the same author found an imperfectly-preserved *Montlivaltia*, parasitic on a *Modiola* in the Black Shales, during the construction of the Penarth Docks (*ibid.* vol. xl, 1884, p. 363). Charles Moore obtained from his 'Flinty bed' at Beer Crowcombe, Somerset, a single specimen of a coral, probably a species of *Montlivaltia* (*ibid.* vol. xvii, 1861, p. 511).

Rhætic beds are preserved between two faults, as recorded in the Geological-Survey Memoir, but they have been omitted—no doubt inadvertently—from my copy of the map.

### iii. Cowbridge to Pyle.

At most localities between Cowbridge and Pyle the Black Shales and intercalated sandstone-bands, which usually constitute the deposit laid down during the *contorta*-age, are replaced by massive sandstones containing few fossils; while, during the time when the Upper Rhætic was deposited, a greenish marl with red streaks was formed.

What details concerning the Rhætic can be obtained in the neighbourhood of St. Mary Hill have been recorded by Mr. Tiddeman<sup>1</sup>; it is, therefore, sufficient to state here that the arenaceous element predominates over the argillaceous.

The road between the railway near Coychurch and Coity runs along the outcrop of the Rhætic, of which there are several exposures; as, for instance, seven-tenths of a mile north-west by west of Coychurch Church, and again in the road at Simondston. In the village of Coity itself, sandstones and shales of a greenish tint (but mottled red in places), and full of *Modiola minima* (?) Sow., are seen in a road-cutting near the Castle.

### (A) Hendre, near Pencoed.

Between Hendre and Pencoed the Rhætic has been disturbed by two faults, that on the north letting it down against clayey shales belonging to the Millstone Grit. The Hendre brick-kilns are situated on the Keuper Marls. At a slightly-higher level to the north are the Rhætic sandstones, faulted against the Millstone Grit. A passage driven from the brickworks to the bottom of the clay-pit passes through the Rhætic sandstone, and from such fissile rock numerous ill-defined casts, of a lamellibranch of *Schizodus*-facies, were obtained. The Keuper Marls are excellently exposed in a pit adjoining the works.

A little to the east of the Hendre brickworks are two quarries in which massive Rhætic sandstone is worked. *Pullastra arenicola* and scales and fragmentary bones of *Gyrolepis Alberti* have been collected in this neighbourhood by Mr. Tiddeman, who has also given the following record of the sequence of deposits<sup>2</sup>:—

		Thickness in feet.
LOWER RHÆTIC.	Sandstone, white, fine-grained, massive below and more thinly-bedded and yellowish above .....	seen 30
	{ a. Sandy beds .....	3
UPPER KEUPER.	{ b. Green and yellow marl.....	15
	{ c. Hard marl, with 'race' and gypsum .....	2
	{ d. Clayey red marl.....	2
	{ e. Clay and marl; proved in a well .....	30

<sup>1</sup> 'Summary of Progress of the Geological Survey for 1899' (1900) p. 129 and 'The Geology of the South-Wales Coalfield: Pt. vi—The Geology of the Country around Bridgend' Mem. Geol. Surv. 1904, pp. 50, 51.

<sup>2</sup> 'Summary of Progress of the Geological Survey for 1899' (1900) p. 129 and 'The Geology of the South-Wales Coalfield: Pt. vi—The Geology of the Country around Bridgend' Mem. Geol. Surv. 1904, p. 50. See also his pamphlet on the 'Quarella Quarries,' Bridgend, 1893.



## (B) Quarella Quarry, Bridgend.

North of Bridgend are the well-known Quarella Quarries, where pale-green and white Rhætic sandstones are worked, the rock being very suitable for building-purposes. A single block from Bed *c* (of the sandstone-deposit) of the appended record measured  $72 \times 53 \times 44$  inches, and must have weighed about a ton and a half. The deeper quarry, and that which yields the more satisfactory section, is situated on the south side of the lane :—

		Thickness in feet   inches.	
OSTREA- BEDS.	Limestone, grey .....	0	6
	Shale-parting .....	0	1
	Limestone .....	0	3
	Shales, bluish-grey and brown .....	0	4
RHÆTIC.	1. Shales, hard, passing into hard bluish-grey limestones with conchoidal fracture .....	maximum	7
	2. { <i>a.</i> Shale, black and brown, clayey .....	0	4
	<i>b.</i> Shale, hard .....	0	4
	<i>c.</i> Marls, greenish and yellowish .....	1	8
	3. Limestone, argillaceous, nodular: 3 to 5 inches .....	0	4
	4. Green and yellow sandy marls; almost a fine sandstone in places .....	about	6   6
	5a { <i>a.</i> Sandstone, pale-green and white, rather broken up...	4	4
	<i>b.</i> Sandstone .....	3	4
	<i>c.</i> Sandstone .....	4	0
	15(?) { <i>d.</i> Sandstone .....	4	0
	<i>e.</i> Sandstone, more flaggy, and therefore in thinner layers, seen .....	8	6

The first notice of this section is contained in Tawney's paper 'On the Western Limit of the Rhætic Beds in South Wales & on the Position of the "Sutton Stone."' He regarded the sandstone-beds as belonging to the Keuper, while '6 feet of green sandy marls' he doubtfully referred to the Rhætic.<sup>1</sup> Charles Moore observed (Quart. Journ. Geol. Soc. vol. xxiii, 1867, p. 513) that

'in the valley west [north?] of Bridgend the Keuper Sandstones are largely worked, but their succession upwards into the Lias is not well exposed.'

H. W. Bristow, however, corrected this error (*ibid.* p. 205):

'the sandstones quarried for building and grindstones . . . are not situated at the base of the Keuper, as stated by Mr. Tawney, but are in the upper part of the Rhætic Series, overlain by Lias crowded with the characteristic *Ostrea liassica*.'

Whichever subdivisions of the Rhætic are represented here, and in the absence of fossils (except for a *Lima*) it is difficult to decide, it is obvious that we have the equivalents of nearly the whole series. The stratum distinguished as 1 much resembles the Cotham-Marble equivalent; while the nodular limestone (3) is very suggestive of the *Estheria*-Bed. From the limestones capping the section Mr. Tiddeman obtained *Ostrea liassica* and *Pleuromya*.<sup>2</sup>

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxii (1866) p. 72.

<sup>2</sup> 'Summary of Progress of the Geological Survey for 1899' (1900) p. 130 and 'The Geology of the South-Wales Coalfield: Pt. vi—The Geology of the Country around Bridgend' Mem. Geol. Surv. 1904, p. 51.

Sandstone, from which Rhætic fossils have been obtained, has been worked near the Angeltown Asylum, and (more recently) for building the church at Pen-y-fai.

The section in the railway-cutting at Cwrt-Colman is now for the most part overgrown, but the details recorded by Tawney show (1) that there is an increase in the proportion of the shale-deposit to the sandstone as compared with the Quarella section, and (2) the presence of a recognizable bone-bed (Quart. Journ. Geol. Soc. vol. xxii, 1866, p. 70). Massive sandstone-beds, however, are still to be seen on the south side of the line. Near this cutting, in a road-section south of Melin Cwew, certain information concerning the upper portion of the Rhætic has been obtained by Mr. Tiddeman.<sup>1</sup>

### (C) Stormy Down.

The picturesque and breezy moorland known as Stormy Down is covered with large masses of Rhætic sandstone, and is broken with many scattered openings, most of which have been made in search of sand for silica-bricks. In a long line of excavations the following sequence may be observed:—

	Thickness in feet inches.	
a. Sandstone with an uneven base: 10 to 12 feet seen .....	11	0
b. Marl, green and yellow, clayey. Soft and hard layers alternate. They appear to have been slightly contorted previous to the deposition of the superincumbent sandstone, as soft arenaceous matter fills up the miniature synclines. A little lignite occurs near the base .....	about	1 10
c. Marl, greyish-green; full of plant-remains .....	1	0
d. Clay, brown .....	0	2
e. Marl, grey and brown .....	seen	0 6
[Apparently this deposit extends some feet deeper.]		
f. Sandstone of considerable thickness ['Tea-Green Marls' ?].		

Tawney (*op. cit.* pp. 70, 71) has recorded *Pteria* (*Avicula*) *contorta* from the marls intervening between the sandstone-deposits on Stormy Down; while from the sandstone (but not *in situ*) I have obtained casts of *Schizodus*, *Myophoria*, *Natica pylensis*, Tawney, and *Cylindrites oviformis*, Moore, together with a fragment of the ichthyodorulite of a *Hybodus*.<sup>2</sup> By the roadside near Llangewdd Court large masses of sandstone were found to contain numerous plant-remains.

### (D) Stormy-Down Cement-Works.

At the time of my visit to the Stormy-Down Cement-Works water had accumulated in the pit, and so it was only possible to examine certain of the Lower Liassic beds. The lower beds are, therefore, tabulated on Mr. H. B. Woodward's authority.

<sup>1</sup> 'The Geology of the South-Wales Coalfield; Pt. vi—The Geology of the Country around Bridgend' Mem. Geol. Surv. 1904, p. 53.

<sup>2</sup> See also 'Summary of Progress of the Geological Survey for 1899' (1900) p. 131; 'The Geology of the South-Wales Coalfield; Pt. vi' Mem. Geol. Surv. 1904, p. 56; and Quart. Journ. Geol. Soc. vol. xxii (1866) p. 71.

Thickness in feet inches.

LOWER LIAS.	1. Clay, with yellow and hard grey limestone-nodules; <i>Pentacrinus</i> - ossicles, <i>Pseudodiadema</i> -radiole?; <i>Lima</i> ( <i>Plagiostoma</i> ) <i>gigantea</i> , <i>L. (Radula) pectinoides</i> , <i>Unicardium cardioides</i> , <i>Modiola minima</i> , <i>Ostrea cf. liassica</i> , <i>Pholadomya glabra</i> ; <i>Dentalium etalense</i> , gasteropods; <i>Psiloceras Johnstoni</i> ..... seen	3	6
	2. Limestone .....	0	5
	3. Shale, dark .....	0	7
	4. Limestone, yellowish, nodular; <i>Psiloceras Johnstoni</i> .....	1	8
	5. Shale, dark .....	0	3
	6. Limestone, bluish, mixed with shaly matter.....	2	7
	7. Shale, dark, usually persistent ..	0	6
	8. Hard blue limestone, with a little shaly matter; <i>Ostrea liassica</i> , <i>Psiloceras planorbis</i> [seen in 1905, 8 feet; add 10]	18	0
	9. Conglomerate-bed .....	0	10
	10. Limestone-shales .....	0	8
	Hard compact limestone (resembling the Sun-Bed) .....	0	10
	Shaly parting.		
	Hard, compact, and rather shaly limestone.....	0	8
	Black shales, with thin bands of limestone; <i>Pecten valoniensis</i> .....	1	0
	Grey and greenish marls, with hard nodules (formerly used for cement)..... seen to a depth of	3	6

[A specimen of *Caloceras intermedium* (Portlock) was found, but not *in situ*.]

In addition to Mr. H. B. Woodward,<sup>1</sup> several other authors have described this section. H. W. Bristow wrote:

'The section at the Stormy Cement-Works . . . shows about 20 feet of ordinary Lias limestone and shale, resting upon 2 feet of a hard, siliceous, and shelly blue conglomerate, under which occur from 12 to 15 inches of pale argillaceous limestones, breaking with a smooth conchoidal fracture, and which I believe to represent the "White Lias" or uppermost member of the Rhatic Series.' (Quart. Journ. Geol. Soc. vol. xxiii, 1867, p. 204.)

Charles Moore, in his valuable contribution to our knowledge of the Mesozoic littoral deposits, commented upon the fact that

'When compared with the West-of-England section, the Rhatic beds at this spot are very insignificant. A single bed of black marl containing *Pecten valoniensis* and other Rhatic shells succeeds the variegated marls, and upon this a dark limestone 4 inches, and next a bed (in texture very similar to the "White Lias") 2 feet thick. The *Ostrea*-beds then follow . . .' (*Ibid.* p. 520.)

In 1884 the late R. F. Tomes recorded in the pages of the Quarterly Journal (vol. xl, p. 359) the following details of the strata below the *Ostrea*-Beds:—

Thickness in feet inches.

'Hard conglomerate, in all respects like the "Guinea"-Bed of Binton.....	2 to	3	0
Fine-grained nodular limestone, with a conchoidal fracture, and very much resembling the <i>Estheria</i> -Bed.....	1 to	2	0
Dark-grey Rhatic shale.....	1	6	
Greenish, compact Keuper Marl, forming the bottom of the pit.'			

<sup>1</sup> 'The Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iii (1893) p. 114.

There is obviously some peculiarity about the stratigraphical sequence in this section. Observers are agreed that at the base there are greenish marls: Tomes mentioned them as belonging to the Keuper; Mr. H. B. Woodward as belonging to the Rhætic. If they belong to the latter, then they must correspond either to the green marls above the sandstone at the Quarella Quarry (p. 407), or to some bed occupying the stratigraphical position of that which is lettered *b* in the section on Stormy Down (p. 408). If it be considered that they correspond to the former, the presence of 'black shales, with thin bands of limestone; *Pecten valoniensis*,' in the foregoing section at Stormy-Down Cement-Works (p. 409), needs explanation; and again, if to the latter, the absence of the sandstone-deposit, such as that seen on Stormy Down (Bed *a*) requires accounting for. Charles Moore, as already mentioned, commented upon the insignificance here of the equivalent of the Rhætic of the West of England. Tomes thought that the greenish marls belonged to the Keuper, and if his surmise be correct the Rhætic Black Shales probably rest thereupon non-sequentially, for the *Pecten*-Beds occur at some height above the base of the series, where the sequence is complete.

Not having had the opportunity of examining the beds which may possibly correspond to those that compose the greater portion of the Upper Rhætic at other localities, I think that it is undesirable to offer any suggestions.

The Rhætic Beds in the neighbourhood of Pyle are largely represented by sandstones. In the recently-published Geological-Survey Memoir on the district, there is an excellent account of the sections available, and to that account I have nothing to add.<sup>1</sup> Attention, however, may be directed to the fact that Tawney appears to have studied beds higher in the series than any seen of late years, because he makes mention of limestones 'which . . ., from their appearance and conchoidal fracture, remind one of the Cotham Marble . . .'<sup>2</sup> He prefaced his observations on this tract with the remark that 'The above-mentioned patch [was] sufficiently described by Mr. Bristow,' and referred the reader to Rep. Brit. Assoc. 1864 (Bath) Trans. Sections, p. 50. In the place cited there is no mention made of this Pyle, but Pyllle Hill (Bristol) is referred to as a locality visited by Bristow, for the purpose of making a detailed section of the Rhætic Series.

#### IV. ADDITIONAL OBSERVATIONS ON THE SULLY BEDS.

It is generally admitted that, towards the close of Keuper times, there was a great inland sea covering a large part of England, which by degrees evaporated. As Mr. A. Rendle Short has pointed out, the conditions were probably desertic, and therefore over that area there would be a more or less uniformly-horizontal surface, with gently-shelving shores, and occasional deeper pools and

<sup>1</sup> 'The Geology of the South-Wales Coalfield: Pt. vi.—The Geology of the Country around Bridgend' Mem. Geol. Surv. 1904, pp. 54-55.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxii (1866) p. 70.

channels.<sup>1</sup> This inland sea, at the close of the epoch, had been reduced by evaporation to a few comparatively-shallow lakes surrounded by flats of marl.

One of these lakes certainly existed in the Lavernock district, and, as I have already pointed out, it would be in such areas that transition-beds between the Keuper and the Rhætic should be sought for.<sup>2</sup> This lake was deepened, and its limits further restricted, by earth-pressures which occurred at the close of the Keuper Epoch.

It is difficult, at present, to decide whether the earth-pressures were more intense at the commencement or at the close of the time when the Sully Beds were deposited.

It is well-known that towards, or at the close of, the Carboniferous Period, earth-pressures affected the Palæozoic rocks of most parts of the world, and among them Glamorganshire, and caused the strata to be thrown into a number of anticlines and synclines. The folds in Glamorganshire have been mapped and admirably described by Messrs. Strahan & Cantrill, the main axis being distinguished by these authors as the Cardiff-Cowbridge anticline. As observed by Mr. Strahan, this anticline as far west as Pendoylan was simply a broad arch, but in that neighbourhood became compound. Mr. Cantrill has shown the position of the subsidiary anticlinal fold: it trends a little north of east and south of west, and brings to the surface at Stalling Down, near Cowbridge, quartzitic and pebbly beds belonging to the Old Red Sandstone.

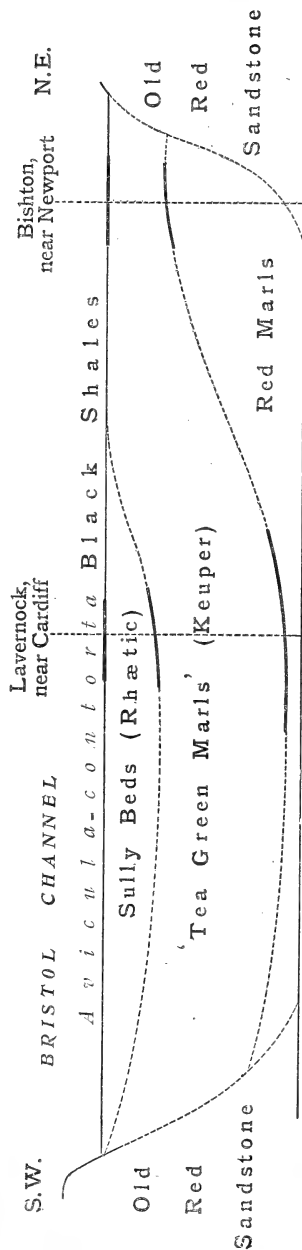
The movements which occurred at the close of the Keuper Epoch, and affected the newly-formed conglomerates and marls, were probably of upheaval along old anticlinal axes, although of course they need not, and it would appear did not, agree with these precisely in position in every case. One of the main axes of elevation at this time, however, was apparently along the line of country traversed by the subsidiary pre-Triassic anticline referred to above. On the hillside to the south of Aberthin, near Cowbridge, rock thought to be Lower Lias is shown in the Geological-Survey Map to rest directly upon the Keuper; and between this outlier and Cowbridge there is another outlier of the same rock, which is depicted as resting upon the littoral Keuper. The Rhætic has been shown by the railway-cuttings at Cowbridge to intervene at those particular localities between the littoral modifications of Keuper and Lower Lias; but usually in the Cowbridge outlier the Lower Lias rests directly, and therefore non-sequentially, upon the Keuper. Similar phenomena are observed at Llanbleiddian—a village near Cowbridge.

Now, if deposition had continued unchecked from Keuper to Liassic times, then everywhere the sequence would have been—Keuper, Rhætic, and Lias; we should not have seen Lias resting directly upon Keuper. Only two explanations can be suggested: either the Rhætic has been deposited and subsequently removed (but in

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lx (1904) p. 186.

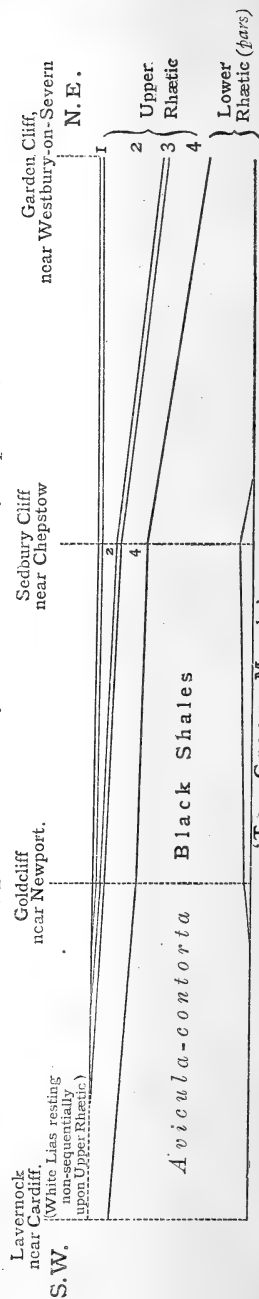
<sup>2</sup> *Ibid.* p. 357.

Fig. 3.—Diagrammatic section showing the relationship of the Pteria (Avicula)-contorta Black Shales to the subjacent deposits. (See p. 413.)



[Horizontal Scale: 1 inch = 8 miles (about) Vertical Scale: 1 inch = 5 feet.]

Fig. 4.—Diagrammatic section showing the relationship of the Lavernock White Lias to the Upper Rhætic, etc. of Gloucestershire. (See p. 415.)



[Horizontal Scale: 1 inch = 8 miles. Vertical Scale: 1 inch = 25 feet.]

pre-Liassic times), or the Rhætic has not been deposited. In either case, it seems to me that it is necessary to invoke the assistance of earth-movements to explain matters; but, taking all the facts available into account, it would certainly seem that at the localities in question the Rhætic had not been deposited, owing to an elevation which was initiated about the time of the deposition of the Sully Beds. On the westerly continuation of the Cardiff-Cowbridge anticline at Bevos, near Tythegston, it is interesting to notice that the relations of the Lias to the Keuper also suggest that the above is the correct interpretation of the phenomena; while at Sutton again it is very doubtful whether the Keuper Conglomerate was ever parted by a Rhætic deposit from the Sutton Conglomerate.<sup>1</sup>

In the stretch of water which extended into the Lavernock district, and the outlines of which had been modified by the earth-pressures referred to above, the Sully Beds were formed, while the 'Tea-Green Marls' at certain other localities were undergoing subaërial denudation. When the Rhætic ocean gained access to the British region it spread over the Lavernock area; its waters mingled with those of the Lavernock lake; the sediment too was commingled, and the resultant deposit has the peculiar lithic structure which characterizes Etheridge's 'Grey Marls' and the upper portion now denominated the Sully Beds. The appended diagram (fig. 3, p. 412) will help to elucidate my views as regards the relationship of the *Pteria (Avicula)-contorta* Black Shales to the subjacent marls and Sully Beds. Throughout the period during which the Sully Beds were in process of formation, earth-pressures may have affected the rocks, and it is especially desirable that exact records should be kept of any sections showing the junction of these beds with the overlying Black Shales, in order to see whether there is definite evidence of any overlap of the upper strata of the Sully Beds on to the 'Tea-Green Marls.'

It appears imperative that these Sully Beds should be grouped with the Rhætic, and consequently a certain portion of the 'Tea-Green Marls,' as defined during the re-survey of the district (1892-1901), must be assigned to that series and removed from the

<sup>1</sup> The debated question as to the age of the Sutton Stone is now a thing of the past: 'the whole of these beds may be regarded as the basement-beds of the Lower Lias, representing the *Ostrea*-Beds and other portions of the zone of *Ammonites planorbis*, and including perhaps portions of the zone of *A. angulatus*' (H. B. Woodward, 'The Geology of the South-Wales Coalfield: Pt. vi' Mem. Geol. Surv. 1904, p. 62). I concur with this view. A little to the west of the Caves, below West, near Southerndown, a quarry (now disused) had been opened out in beds about the junction of the Sutton Conglomerate and Stone, and from the spoil-heap were collected *Chemnitzia* (fragment), *Anomia*? (with *Serpula*), *Astarte* (*Cardita*? *rhomboidalis*, Tawney), *Cardinia regularis*, Terq. (= *C. suttonensis*, Tawney), *Gryphæa*, *Lima* (*Ctenostreon*) *tuberculata*, Terq., *Lima* (*Plagiostoma*) sp. (small), *Lima* (*Radula*) *hettangiensis*, Terq. (juv. = *L. subduplicata*, Tawney), *Ostrea multicostrata*, Münster, *Plicatula intus-triata*, Emmrich, *Pecten valoniensis*, Defrance, *Mytilus imbricato-radiata*, Tawney, *Lithophagus* sp., *Serpula* (?), and *Astrocæmia gibbosa* (Duncan). *Lima Terquemii* is not uncommon, and this fossil alone demonstrates the non-Rhætic and the non-White Lias nature of the deposit in which it occurs.

Keuper. No mention is made in the Geological-Survey publications of the abundant occurrence of *Ostrea* in the 'Tea-Green Marls' at St. Mary's-Well Bay, Sully: it is observed that these marls

'are distinguished from the Rhætic formation by the fact that they have hitherto proved to be totally unfossiliferous in South Wales, except for the occurrence of a bone-bed at Goldcliff.'<sup>1</sup>

This statement, however, is modified in a subsequent part of the same memoir,<sup>2</sup> but the same classification is adhered to. Although I have been compelled, from the palæontological evidence, to suggest that the Sully Beds be classed with the Rhætic, I nevertheless quite agree that the line of demarcation between Keuper and Rhætic decided upon by the officers of the Geological Survey is the most satisfactory for their purpose, because it is then possible to indicate on the map where the lithic change takes place.<sup>3</sup>

Renewed earth-movements occurred before the deposition of the Rhætic Black Shales, and brought about conditions suitable for a slight erosion of the uppermost stratum of the Sully Beds. In the Penarth-Lavernock section, indications of such an erosion are most apparent.

I would here direct attention to the fact that Mr. F. T. Howard, F.G.S., is of opinion that

'in South Wales, at least, there was a slight upheaval instead of a subsidence just at the close of the Trias Period (immediately preceding the subsidence of Rhætic and Liassic times, about which the evidence is indisputable). We see at once that the newly-formed Trias beds might be raised into dry land, and immediately attacked by the various agents of denudation.'<sup>4</sup>

#### V. CONDITIONS OF DEPOSITION OF THE RHÆTIC BLACK SHALES.

So far as is known at present, while the Black Shales or sandstones containing *Pteria* (*Avicula*) *contorta* were being deposited in the Glamorganshire district, no appreciable earth-movements occurred.

<sup>1</sup> 'The Geology of the South Wales Coalfield: Pt. i—The Country around Newport, Mon.' Mem. Geol. Surv. 1899, p. 70.

<sup>2</sup> *Ibid.* Pt. iii—'The Country around Cardiff' 1902, p. 41.

<sup>3</sup> Since this paper was written, that dealing with the Rhætic rocks of Monmouthshire has been communicated to the Geological Society. In the discussion which ensued (Quart. Journ. Geol. Soc. vol. lxi, 1905, p. 384) Mr. Strahan said that he had been unable to identify the 'Grey Marls' of Etheridge, and doubted whether any such subdivision of the 'Tea-Green Marls' could be made. The palæontological evidence set forth in the present paper requires such a division; but, of course, the actual line of demarcation between the Sully Beds and the 'Tea-Green Marls' must be more or less arbitrary, and governed solely by palæontological considerations. Mr. Strahan also doubted whether there was any overlapping of the 'Tea-Green Marls' by the *Avicula-contorta* Shales, and remarked that they varied but little in thickness over the whole region. According to the Geological-Survey publications, the 'Tea-Green Marls' at Lis-Werry measure 13 feet ('Geology of the South Wales Coalfield: Pt. i—The Country around Newport, Mon.' Mem. Geol. Surv. 1899, p. 74) and at Lavernock 44½ feet (*ibid.* Pt. iii—'The Country around Cardiff' 1902, p. 54)—a difference of 31½ feet.

<sup>4</sup> Trans. Cardiff Nat. Soc. vol. xxix (1896-97) pp. 65-66.



In the neighbourhood of Bridgend, a considerable deposit of sandstone was made while black sediment was being laid down around Lavernock. The very different nature of these contemporaneous deposits is to be accounted for, mainly by the fact that there was only imperfect connection between the two areas of deposition: land, composed of Palæozoic rocks, intervened.

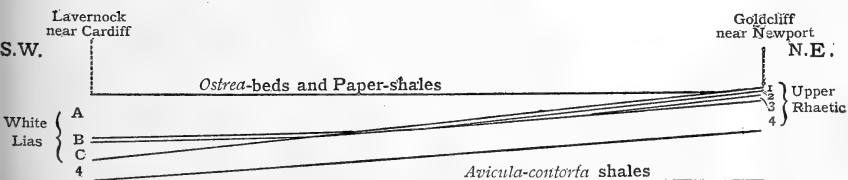
There is evidence (which will be quoted shortly), however, to show that near the commencement of the Upper Rhætic 'Age' the deposits in the Lavernock area were elevated, and a stretch of water separated-off to the north. Theoretically, this stretch of water may be regarded as having been connected with that in which the Upper Rhætic beds now visible at Bishton, near Newport,<sup>1</sup> were deposited. This view explains the similarity noticed between the beds distinguished as 3 at the Quarella Quarry, Bridgend, and Bishton, and likewise between the remaining similarly-notated deposits.

The effects of these earth-movements were not merely local; by the elevation of certain areas, shallow lagoons were formed in others, initiating conditions suitable for the existence of *Estheria*. While the Upper Rhætic Beds 3 to 1 were in the course of formation, the Lavernock area was above sea-level; the marl-deposit (4) was subjected to subærial denudation and somewhat fissured (fig. 4, p. 412).

## VI. ON THE WHITE LIAS OF GLAMORGANSHIRE, AND ON THE STRATIGRAPHICAL POSITION OF THE WHITE LIAS.

A gradual subsidence in the Lavernock area, accompanied by the reverse movement to the north, allowed again of deposition, and into the fissured marls (4) gritty material was washed. The relations of the White Lias and the Upper Rhætic Beds may be represented as shown in fig. 5, below.

Fig. 5.—Diagrammatic section showing the relationship of the White Lias to the Upper Rhætic in the Cardiff district.



In the Bath district, the sea in which the well-known White Lias was deposited was deeper than at Lavernock. At the latter locality, the various lamellibranchs are usually found grouped upon the surfaces of the limestone-bands: *Plicatula intus-striata*,

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 377-78.

*Pl. hettangiensis*, and *Lima valoniensis* being especially abundant. A stratum which probably represents the Sun-Bed completes the equivalent of the White Lias of the Bath district: the representative of Bed A of the Lavernock and Barry sections is only found over a restricted area, and probably indicates a deepening of the sea in this neighbourhood, caused by renewed earth-pressures.

During the period when the White-Lias limestones and shales (A & B, Lavernock) were being deposited, the Cotham Marble in certain localities was hardened, broken up, and cemented into a conglomerate—for example, at Sedbury Cliff, near Chepstow. As remarked by Dr. Arthur Vaughan,

‘The time occupied by the hardening of the Cotham layer [at Sedbury Cliff], its destruction, and subsequent cementation into a conglomerate may be considered to correspond roughly to the time of deposition of the White Lias in the areas on the south and east.’ (Quart. Journ. Geol. Soc. vol. lix, 1903, p. 397.)

It is interesting to observe also that the same author thought that

‘At Sedbury Cliff the deposition of the Cotham Marble must have been succeeded by an elevation of the floor, which produced the breaking-up of the Cotham-Marble layer *in situ*.’ (*Ibid.* p. 398.)

At the time when the Lower Liassic ‘Paper-Shales’ were formed, the bathymetric conditions were about the same in the West of England.

In the description of the various sections in this shire, reference has been made to the stratigraphical position of the White Lias, and it will have been noticed that this deposit is considered to come above the Cotham Marble. Recent work accomplished by several geologists in the Bristol district has demonstrated that such is its correct stratigraphical position.

As long ago as 1864, Bristow & Etheridge, in their account of the Rhætic beds at Penarth, referred to ‘bands of limestone and indurated marl (in brown shale),’ which they considered might be ‘equivalent to the “White Lias.” . . . The place of the Cotham Marble (not observed here),’ they added, ‘is at the base of this group of beds.’ (Geol. Mag. vol. i, p. 237.)

It has been remarked recently that the denomination White Lias is a useful stratigraphical term for the Upper Rhætic Beds in the region extending southwards from Bath (Geol. Mag. 1905, p. 79).

Since the term Upper Rhætic has been applied by different authors to obviously non-contemporaneous strata, it is desirable to define exactly to what beds it has been applied in the present paper. The ‘Upper Rhætic’ of my records of the sections in North-West Gloucestershire, and those at Wood Norton (near Evesham), Sedbury Cliff (near Chepstow), and elsewhere, is not the equivalent of the White Lias.

At Wainlode Cliff, on the banks of the Severn between Gloucester and Tewkesbury, no White Lias is present: the Paper-Shales rest directly upon the *Pseudomonotis*-Bed, as shown in the following section:—

		Thickness in feet inches.		
OSTREA-BEDS. Limestone, hard, blue.....		0	4	<i>Ostrea liassica</i> , <i>Modiola minima</i> .
Paper-Shales, brown and grey, finely laminated, with an intermittent limestone-band .....		1	3	<i>Pseudomonotis fallax</i> , <sup>1</sup> <i>Darwinulialiasica</i> , <i>D. liassica</i> var. <i>major</i> (teste Brodie & Prof. T. R. Jones).
UPPER RHETIC.	1. Limestone. <i>Pseudomonotis</i> -Bed. 'Insect-Limestone.' Hard, dark-grey and blue .....	0	5	<i>Modiola minima</i> , <i>Ostrea</i> (teste Brodie); insects; fish-scale.
	2. Shales, blue and brown, laminated, weathering into a marly clay .....	5	2	<i>Lycopodites lanceolatus</i> ; <i>Estheria minuta</i> var. <i>Brodieana</i> ; ostracoda (teste Brodie); fish - remains and shell-débris.
	3. Limestone. <i>Estheria</i> -Bed. 'Cypris'-Bed. Hard, yellow, nodular; arborescent markings; irregular fracture...	0	6	<i>Modiola minima</i> , <i>Schizodus Ewaldi</i> , <i>Cardium cloacinum</i> .
	4. Shales, pale, greenish-yellow, coarsely laminated, marly .....	6	0	
LOWER RHETIC.	<i>Pteria</i> ( <i>Avicula</i> )- <i>contorta</i> Zone.			

Near Chase Hill, Wickwar, the thin flaggy limestones of the *Ostrea*-Beds rest directly upon the Cotham Marble,<sup>2</sup> and in that neighbourhood the bed frequently contains *Pseudomonotis fallax* in abundance. But to the south, in the railway-cutting at Lilliput, near Chipping Sodbury, the sequence is as follows:—

		Thickness in feet inches.		
OSTREA-BEDS. Thin flaggy limestones, separated by thin shales .....		3	0	<i>Ostrea liassica</i> , <i>Modiola minima</i> , and <i>Pleuromya</i> .
WHITE LIAS. B. Compact cream - coloured limestone .....		1	0	
UPPER RHETIC.	1. Cotham Marble .....	0	5	
	2. Grey shale, containing plant-beds at 15 and 18 inches from the top.	2	3	<i>Darwinula</i> & <i>Estheria</i> .
	3. Brown, unfossiliferous shale .....	1	0	
	4. Argillaceous limestone.....	0	6	
LOWER RHETIC.	4. Brown or grey shale, with lenticular beds and concretions of argillaceous limestone at two or three levels .....	5	0	Fragmentary shells, <i>Cardium cloacinum</i> , <i>Modiola</i> .
	<i>Pteria</i> ( <i>Avicula</i> )- <i>contorta</i> Zone.			

In the foregoing section, the position of the White Lias is clearly shown: it occurs above the Cotham Marble.

Some 5 miles south-south-west of Lilliput the White Lias is seen to have increased in thickness; for, in a quarry by the side of the

<sup>1</sup> *Pseudomonotis decussata* of my previous papers.

<sup>2</sup> Geol. Mag. 1904, p. 534.

drive at Blue Lodge, near Siston, the White-Lias beds exposed are as follows:—

		Thickness in feet inches.			
OSTREA-BEDS.	Limestones, thin, with clay-partings.			{ <i>Ostrea liassica</i> , <i>Protocardium Philippi- anum</i> .	
	Clay .....	0	2		
	Limestone, in two beds with clay-parting.	0	3½	{ <i>Pholadomya glabra</i> .	
	Clay, full of <i>Ostrea</i> : ½ to 1½ inches ...	0	1	{ <i>Ostrea liassica</i> .	
	Limestone, sometimes in two beds .....	0	4	{ <i>Protocardium Philippi- anum</i> common.	
	{ Clay or limestone .....	0	1		
	{ Limestone, often inconspicuous .....	0	1		
WHITE LIAS.	Brown and dark clay: 3 to 6 inches .	0	4		
	B. Sun-Bed.....	1	1		
	Clay .....	0	0½		
	Limestone, thin.....	0	2½		
	Limestone .....	0	7		
	Clay-parting .....	0	0½		
	Limestone .....	0	2½	{ <i>Ostrea liassica</i> , <i>Lima valoniensis</i> , <i>Modiola minima</i> , <i>Protocardium Philippi- anum</i> , <i>Plicatula intus- striata</i> .	
	Shaly deposit .....	0	1		
	C. Rubbly beds .....	seen	1		
	[COTHAM MARBLE.]				

The Sun-Bed is exposed in the quarry, but it will be observed that below it is a deposit of which a thickness of 2 feet 2 inches is seen, without any evidence of the Cotham Marble. But no doubt that stratum would be found, if the excavation were a little deeper; and then, below again, would occur the grey marls of the Upper Rhætic, such as those seen in close proximity to the Carboniferous Limestone seven-tenths of a mile south by 5° east of Abson Church.<sup>1</sup>

The rubbly beds (C in the foregoing section) are interesting. They seem to be present, as a rule, in the Bath district, but are rarely exposed as they are of no industrial value, and quarrying operations are therefore not prosecuted so deep down. These beds are not present in the Lilliput section, but I recently (May 1905) obtained evidence, from débris thrown out of a well, to show that they do extend farther north than Blue Lodge, Siston, where they

<sup>1</sup> At an ochre-working, at the cross-roads near Gatheram Farm, Wick Rocks, the following interesting section is exposed:—

		Thickness in feet inches.			
RHÆTIC.	Light-coloured, grey and yellow clay seen	2	9		
	Peculiar deposit of black and brown sandy clay, with impure limestone in places.....	0	3		
	Sandy bed, with more or less angular pieces of grit (the biggest measuring 2×1½×1 inch): ½ to 2 inches.....	0	1	{ ' <i>Sargodon tomicus</i> ' ( <i>Lepidotus</i> ?), <i>Acro- dus minimus</i> (rare), <i>Gyrolepis Alberti</i> , & fragments of bone.	
KEUPER (including 'Tea-Green Marls').	Light-yellow and grey clay, with hard masses of marlstone containing small quartz-pebbles.....	about	2	6	
	Reddish deposit, with yellow streaks...	1	6		
	Yellow stone .....	1	0		
	Reddish stone, with yellow streaks.....	1	3		
	Hard, yellow stone: 5 to 7 inches .....	0	6		
	Working for ochre .....				

are seen at the bottom of the quarry noticed above (p. 418). Unfortunately, this well, which is situated in the orchard at the back of the inn in the village of Codrington, had been sunk some weeks previous to my visit to this part of the country, and the greater mass of the rock which had been excavated had been carted away.

The well is 70 feet deep, and the water-supply good. Those blocks of Lower Lias which were sufficiently compact had been used for walling the sides of the well, so that very little of the rock was lying about. The limestone which could be examined contained small specimens of *Lima gigantea* and *Ostrea liassica*. How great a thickness of Lower Lias was penetrated could not be ascertained. Pieces of a compact cream-coloured limestone showed that the White-Lias Sun-Bed had been proved, together with the sub-jacent, rubbly, fossiliferous White Lias, which contained *Plicatula hettangiensis* (one specimen), *Lima valoniensis*, *Protocardium Philippianum*, *Modiola minima*, Moore, and gasteropoda. Masses of a hard limestone (with a mammillated surface and faint arborescent markings) showed that the Cotham Marble was present, if not in its quite typical form. The remaining Upper Rhætic deposits are apparently similar to those which were exposed in the railway-cutting at Lilliput, and some of the indurated portions contained fish-scales and teeth not uncommonly. Black shales were very much in evidence, and contained a hard dark limestone with *Pecten (Chlamys) valoniensis*, *Pteria (Avicula) contorta*, *Placunopsis alpina* (large), and *Schizodus* (?): also dark, calcareous, very micaceous, and occasionally pyritic sandstone-layers. A number of pieces of Bone-Bed were found. They indicated that the Bone-Bed here was not of the same lithic structure as that at Lilliput, doubtless owing to the fact that it does not rest upon any member of the Carboniferous System or the Old Red Sandstone. This is known from arenaceous 'Tea-Green Marl' having been found among the débris. The Bone-Bed is a dark-grey, micaceous, sandy limestone, with *Gyrolepis Alberti* (scales and teeth?), *Acroodus minimus*, and coprolites of fishes; but it passes into a thin pyritic sandstone containing a few vertebrate-remains. The excavation was terminated in the Carboniferous Limestone.

Just 2 miles in a direction a little east of south of Blue Lodge the White Lias is quarried near Barton Farm, Upton Cheney, the following section being exposed:—

		Thickness in feet inches.			
OSTREA-BEDS.	Clay .....	0	0	{	<i>Ostrea liassica</i> , <i>Pleuromya crow-</i> <i>combeia</i> , Tate non Moore, <i>Protocar-</i> <i>dium Philippianum</i> .
	Limestone, rubbly .....	0	3		
	Clay .....	0	3		
	Limestone: four beds, with clay between the middle two.....	0	7		
	Clay .....	0	4		
	Limestone: five beds, with clay- partings .....	1	0		
WHITE LIAS.	Clay .....	0	4		
	B. Sun-Bed, capping hard cream- coloured limestones .....	4	0		
	[White-Lias rubbly beds.] [Cotham Marble.]				

As I have indicated above, the rubbly beds of the White Lias probably occur not far below the floor of the quarry, and rest upon the Cotham Marble. The strata below the Sun-Bed and above the rubbly deposits at Blue Lodge are 2 feet 2 inches thick (see p. 418): here, however, the equivalent deposit must be of double that thickness, since White-Lias limestones, 4 feet thick, are exposed without any indication of the rubbly beds.<sup>1</sup>

Some 4 miles distant from the Barton-Farm Quarry is the instructive section at Newbridge Hill, on the outskirts of Bath. When I visited the section, the Cotham Marble was the lowest bed that could be studied *in situ*. The following record is compiled from details noted by the Rev. H. H. Winwood, F.G.S.,<sup>2</sup> my own notes being in square brackets:—

		Thickness in feet inches.			
WHITE LIAS.	B. Sun-Bed .....	0	9½	{ Gasteropoda; <i>Lima</i> , <i>Pecten</i> , <i>Plicatula</i> <i>intus-striata</i> , <i>Modiola</i> [ <i>aff. minima</i> , Moore], <i>Myacites</i> [ <i>Pleuro-</i> <i>mya</i> ], <i>Axinus</i> , <i>Cardi-</i> <i>um rheticum</i> [ <i>Pro-</i> <i>tocardium Philip-</i> <i>pianum</i> ], [ <i>Ostrea</i> ].	
	Limestones, with an occasional parting of clay .....	5	1½		
	C. Rubbly limestone with clay- partings, passing downward into bluish bands. Very fossil- iferous towards the base ...	5	0		
	Blue clay .....	0	1½		
	Limestone .....	0	4		
	Reddish-brown clay .....	0	6½		
UPPER RHÆTIC.	[1] Landscape Stone [or Cotham Marble] .....	0	6½	{ <i>Avicula</i> [ <i>Pseudo-</i> <i>monotis</i> ] <i>fallax</i> .  <i>Estheria minuta</i> and traces of vegetable matter in the band about the centre.	
	[2] Light-blue or grey shales .....	3	8		
	[3] Darker - shaded band about the centre .....				
	[4] Light-blue or grey shales .....				

From these few sections it will be observed, (1) that the White Lias comes above the Cotham Marble and below the *Ostrea*-Beds; and (2) that it increases in thickness, as it is traced from north to south. The component beds of the White Lias successively overlap one another, and this implies elevation in the north, depression in the south: a conclusion also arrived at from investigations in Glamorganshire.

## VII. SUMMARY.

(i) The Sully Beds, or the upper portion of Etheridge's 'Grey Marls,' belong to the Rhætic Series, as shown by the fossils, and are distinct from the 'Tea-Green Marls' of the Keuper, which do not contain fossils.

<sup>1</sup> The White Lias is exposed in road-sections at Barrow Hill, about a mile north of the Barton-Farm Quarry; while the junction of the Rhætic and Keuper is seen in the road-cutting a short distance to the west, or some 300 yards east of Wick Forge. A thin deposit of red sand, containing *Acrodus minimus*, *Saurichthys acuminatus*, *Gyrolepis Alberti* (scales), '*Sargodon tomicus*' (*Lepidotus*?), fragments of bones, and small quartz-pebbles, probably represents the Bone-Bed.

<sup>2</sup> Proc. Bath Nat. Hist. & Antiq. F.-C. vol. ii (1871-73) pp. 204-11.

(ii) Descriptions are given of sections, the most important of which are at Lavernock (near Cardiff), Barry, Tregyff (near Cowbridge), Quarella (Bridgend), and Stormy Down.

(iii) Earth-pressures affected the rocks during the formation of the Sully Beds. The *Pteria* (*Avicula*)-*contorta* Black Shales rest with perfect parallelism, but, nevertheless, non-sequentially, upon the Sully Beds.

(iv) Owing to a local upheaval of the Lavernock district, early in the age during which the Upper Rhætic Stage was deposited, only a portion of the lowest bed of that stage is found, and this deposit was subjected to subærial denudation during the accumulation of the remaining Upper Rhætic beds elsewhere.

(v) Subsidence in the Lavernock district allowed of the deposition of the White Lias. As a result, the White Lias rests non-sequentially upon a portion of the lowest Upper Rhætic deposit.

(vi) The White Lias at certain localities in Glamorganshire contains in abundance *Plicatula intus-striata*, *Pl. hettangiensis*, and *Lima valoniensis*. The deposit intervening between the Sun-Bed and the Upper Rhætic near Bath (Newbridge Hill) is over 11 feet thick: at Lavernock the equivalent deposit measures but 2 feet 2½ inches. At the last-named locality, above the probable equivalent of the Sun-Bed, are marls 6 feet 4 inches thick, which are grouped with the White Lias. Above come the Lower Liassic Paper-Shales, succeeded by the *Ostrea*-Beds.

(vii) The Upper Rhætic of North-West Gloucestershire and Worcestershire is not the equivalent of the White Lias of the Bath district: the White Lias comes above the Cotham Marble (the topmost bed of the Upper Rhætic) and below the Paper-Shales, which occur immediately below the *Ostrea*-Beds.

I am much indebted to a number of geologists and others for kind assistance. For the trouble which he took in procuring photographs of the Lavernock sections I have to record a debt of gratitude to Mr. John Storrie (son of the late John Storrie), of Cardiff; while, in obtaining the literature on the Rhætic of the county I have received much help from Mr. H. B. Woodward, F.R.S., Mr. F. T. Howard, F.G.S., Mr. J. Storrie, and Mr. G. H. Dutton, F.G.S. Valuable assistance with regard to some of the fossils has been most courteously accorded to me by the Rev. J. F. Blake, F.G.S., Mr. S. S. Buckman, F.G.S., Mr. E. T. Newton, F.R.S., Mr. A. C. Seward, F.R.S., and Dr. A. Vaughan, F.G.S.; while to Mr. E. B. Wethered, F.G.S., and Dr. C. G. Cullis, F.G.S., I acknowledge my indebtedness for help in certain petrological matters. For assistance in the field-work I tender my best thanks to Mr. E. Talbot Paris; while I feel that any expression of thanks inadequately conveys my gratitude to Mr. J. W. Tutchter for preparing the excellent photographs of fossils from which the figures in Pl. XXXIII were reproduced.

## VIII. PALÆONTOLOGICAL NOTES.

## OSTREA BRISTOVI, Etheridge, MS. (Pl. XXXIII, fig. 4.)

Right valve.—The dimensions of an average-sized specimen are: length 45 millimetres, breadth 55 mm. The greatest length seems to be attained (as a rule) at 23 mm. from the most extended portion of the ventral margin. The valve is flat or slightly convex; the ventral margin regularly convex; while the anterior and posterior margins converge regularly in the direction of the beak, which unfortunately is not preserved in the specimens collected. The test is somewhat thin for an *Ostrea*, and composed of numerous considerably-imbricating layers.

Unfortunately, the preservation of the specimens of this lamelli-branch does not admit of a very exact diagnosis. Mr. E. T. Newton, F.R.S., informed me (*in litt.*) that specimens of this oyster are preserved in the Museum of Practical Geology, Jermyn Street, London, and bear the MS. name of *Ostrea Bristovi*, Etheridge.

Like most of its tribe, this form is difficult to describe; but, on account of its frequent occurrence in the Lavernock area, it seems desirable to have some name wherewith to record it when obtained.

The specimen figured is from the upper portion of the Sully Beds (Rhætic) at Cadoxton (Glamorganshire).

## CARDIUM CLOACINUM, Quenstedt. (Pl. XXXIII, fig. 5.)

1858. 'Der Jura' Tübingen, p. 30 & pl. i, fig. 37.

1856. Oppel, A., & Suess, E., 'Ueber die muthmasslichen Äquivalente der Kössener Schichten in Schwaben' Sitzungsber. k. Akad. Wissensch. Wien, vol. xxi, p. 540 & pl. ii, fig. 2.

1904. Vaughan, A., 'The Rhætic Beds of the South-Wales Direct Line' Quart. Journ. Geol. Soc. vol. lx, pp. 207-208 & fig. 6.

In the immature forms of this shell the costæ are rounded or subacute, and increase in breadth towards the ventral margin; while the intercostal spaces exceed the breadth of the costæ. In the adult forms, however, the costæ are usually broader and flat-topped, while the intercostal spaces are reduced to mere linear grooves.

The first definite record of this shell was at Wainlode Cliff<sup>1</sup>; but since then it has been found at many localities, and was especially abundant at Lilliput, near Chipping Sodbury, on the South-Wales Direct Line. Dr. Vaughan has given an excellent description of the species, elucidated by figures in the text (Quart. Journ. Geol. Soc. vol. lx, pp. 207-208), and has drawn attention to the *Cardita*-like aspect of the shell, which is especially noticeable in the specimens figured in the present paper. Charles Moore, indeed, referred this shell (which he obtained from the railway-cutting at Willsbridge, near Bitton) to the genus *Cardita*, and entered it as such in his section (Quart. Journ. Geol. Soc. vol. xxiii, 1867, p. 498). His specimen is now in the Bath Museum, and came from the Upper Rhætic.

<sup>1</sup> Proc. Cottesw. Nat. F.-C. vol. xiv (1903) table i, facing p. 174.



The specimen figured in Pl. XXXIII was obtained from Bed 5b (3), Lower Rhætic. Section by the roadside near Bishton, near Newport (Monmouthshire).<sup>1</sup>

*PLICATULA INTUS-STRIATA*, Emmrich. (Pl. XXXIII, fig. 1.)

1853. 'Geognostische Beobachtungen aus den östlichen bayerischen & den angrenzenden österreichischen Alpen' Jahrb. der k.-k. geol. Reichsanst. vol. iv, p. 376.  
 1853. Hauer, F. Ritter von, 'Ueber die Gliederung der Trias-, Lias- und Juragebilde in den nordöstlichen Alpen' Jahrb. der k.-k. geol. Reichsanst. vol. iv, p. 738.  
 1864. Dumortier, E., 'Études paléontologiques sur les Dépôts jurassiques du Bassin du Rhône: pt. i.—Infralias' pp. 74-77 & pl. i, figs. 13-16.  
 1861. *Ostrea interstriata*, Moore, C., 'On the Zones of the Lower Lias & the *Avicula-contorta* Zone' Quart. Journ. Geol. Soc. vol. xvii, p. 501 & pl. xvi, fig. 25.

This lamellibranch is too well-known to require any additional description, but it has not been recorded previously from the Penarth or Barry districts; only from beds of later date to the west, as at Bridgend and near Sutton. At Lavernock it is fairly common, while at Barry it is very abundant in the White Lias. I have not recorded it from the Lower Rhætic in Glamorganshire; but that it does occur abundantly in that stage at certain localities (Watchet, for example) I have been able to satisfy myself only recently (June 1905). At Blue Anchor, near Watchet, it is associated with *Pteria (Avicula) contorta*.

*PLICATULA HETTANGIENSIS*, Terquem. (Pl. XXXIII, fig. 2.)

1855. 'Paléontologie de l'Étage inférieur de la Formation liasique de la Province de Luxembourg, Grand-Duché (Hollande), et de Hettange' Mém. Soc. Géol. France, ser. 2, vol. v, p. 326 & pl. xxiv, figs. 3-4.  
 1864. Renevier, E., 'Notices géol. & paléont. sur les Alpes vaudoises: I.—Infralias & Zone à *Avicula contorta* (Étage Rhétien)' pp. 38-39 & pl. iii, fig. 4.  
 1864. Dumortier, E., 'Études paléontologiques sur les Dépôts jurassiques du Bassin du Rhône: pt. i.—Infralias' pp. 73-74 & pl. xii, figs. 4-7, 10.

*Plicatula hettangiensis* has not been recorded previously, to my knowledge, from the White Lias of this county. It is very common at Coldknap, Barry, and Lavernock, and it is difficult to understand how this *Plicatula* has managed to escape detection for so long a time. It is quite possible, however, that it has been recorded under another name (*Ostrea multicostata*?). A specimen submitted for examination to the Rev. J. F. Blake was at once identified with Terquem's fossil.

As remarked by Terquem (*op. cit.* p. 326), and later by Prof. Renevier (*op. cit.* p. 77), this shell presents several varieties in form. One specimen from Barry agreed precisely with the figure given by the latter author.

*LIMA VALONIENSIS* (Defrance). (Pl. XXXIII, fig. 3.)

1825. 'Mémoire géologique sur quelques Terrains de la Normandie occidentale par M. de Caumont, Mém. Soc. Linn. du Calvados [*postea* de Normandie] vol. ii, p. 507 & Atlas, pl. xxii, fig. 7.

This fossil is of frequent occurrence in the White Lias at Lavernock and Barry. A specimen submitted to Dr. A. Vaughan for

<sup>1</sup> See Quart. Journ. Geol. Soc. vol. lxi (1905) p. 378.

comparison with those of the same genus from 'the main *Pecten*-horizon' at Lilliput, near Chipping Sodbury,<sup>1</sup> was returned with the remark—'typical clavellate form.'

## EXPLANATION OF PLATE XXXIII.

[The fossils figured in this plate are preserved in the Author's collection.]

- Fig. 1. *Plicatula intus-striata*, Emmrich.  $\times 2$ .  
White Lias; Coldknap, Barry (Glamorganshire).
2. *Plicatula hettangiensis*, Terquem. Natural size.  
White Lias; Coldknap, Barry (Glamorganshire).
3. *Lima valoniensis*, Defrance.  $\times$  about  $1\frac{1}{2}$ .  
White Lias; Coldknap, Barry (Glamorganshire).
4. *Ostrea Bristovi*, Etheridge, MS. Natural size.  
Sully Beds (Lower Rhætic); St. Mary's-Well Bay, Sully (Glamorganshire).
5. *Cardium cloacinum*, Quenstedt. Natural size.  
Bed 5 b (Lower Rhætic); roadside section, four-fifths of a mile north-north-east of Bishton Church, near Newport (Monmouthshire).

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lx (1904) p. 202.

[For the Discussion, see p. 430.]

FIG. 1.  $\times 2$ .

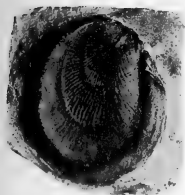


FIG. 2. NAT.  
SIZE.

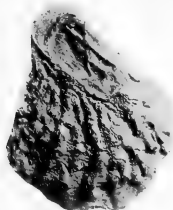


FIG. 4. NAT. SIZE.



FIG. 3.  $\times$  ABOUT  $1\frac{1}{3}$ .

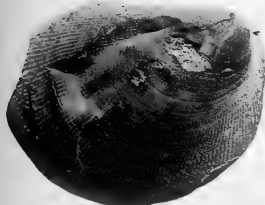
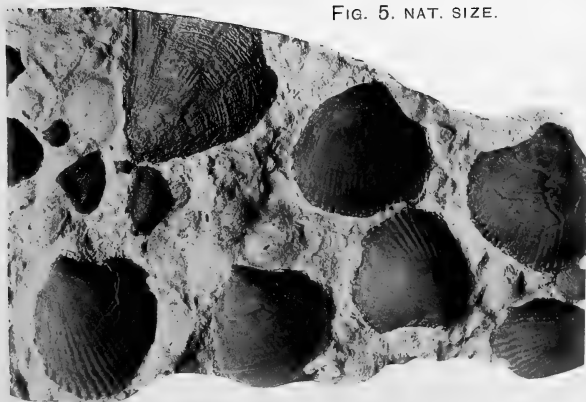


FIG. 5. NAT. SIZE.



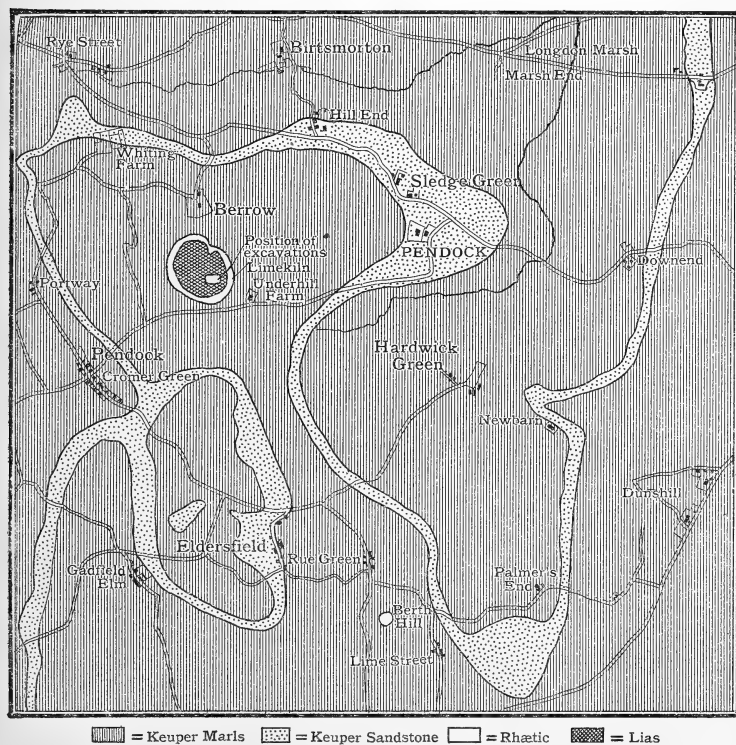
RHÆTIC LAMELLIBRANCHIATA.



19. *On the OCCURRENCE of RHÆTIC ROCKS at BERROW HILL, near TEWKESBURY.* By LINSALL RICHARDSON, F.G.S. (Read May 24th, 1905.)

BERROW HILL (184·8 feet above Ordnance-datum) is a small outlier of Lower Liassic and Rhætic deposits, distant about 2 miles in a south-easterly direction from Chase-End Hill, the southern end of the Malvern Range. It occurs in the centre of a basin-shaped

Fig. 1.—*Geological map of the country around Berrow, showing the geographical distribution of the Keuper Sandstone and the position of Berrow Hill.*



area formed by the Keuper Sandstone, which in this district comes about 215 feet below the base of the Rhætic. By means of this sandstone-deposit, it is possible to trace with very great accuracy the amount of flexuring that these Keuper beds have undergone.

Fig. 2.—Section from north to south, traversing Berrow Hill and Gadbury Bank.

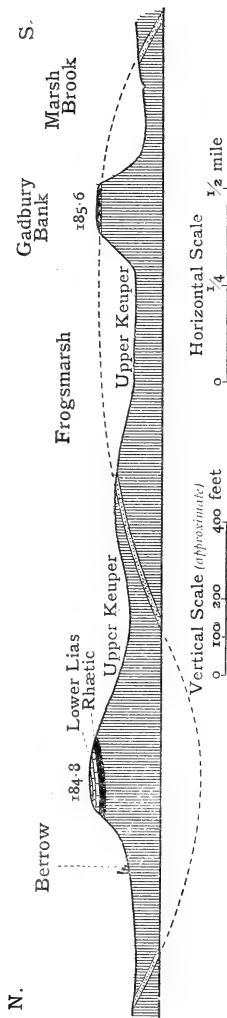
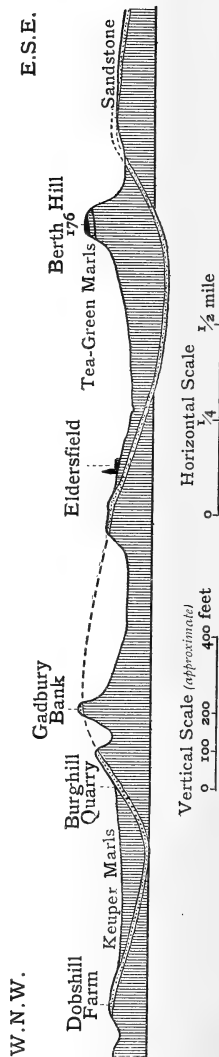


Fig. 3.—Section from west-north-west to east-south-east, traversing Gadbury Bank and Berth Hill.



[The above sections are reproduced by permission of the Cotteswold Naturalists' Field-Club.]

The causes and effects of this flexuring have been dealt with elsewhere,<sup>1</sup> but it may be of interest to mention that at Berrow the sandstone is arranged so as to form a basin; and at Eldersfield—immediately to the south—the numerous exposures show the dip to be quaquaversal. In the past there was a complete ellipsoidal dome, but now the sandstone is much denuded, capping a central boss, while the main mass is at distances varying from a quarter to three-quarters of a mile away. East of the Eldersfield district the rocks are necessarily disposed synclinally: on the northern extension of this axis lies Berrow Hill, and on the southern Berth Hill. This hill, according to Symonds, is capped with Rhætic Black Shales. On the east again the Keuper Sandstone reappears to form an anticline, and then disappears, dipping gently eastward or south-eastward. A reference to the map (fig. 1, p. 425) and sections (figs. 2 & 3, p. 426) will explain much more lucidly than words the flexuring which the Keuper Sandstone has undergone.

In his extremely-useful memoir on the 'Lias of England & Wales,' Mr. H. B. Woodward stated that

'The westerly extension of the Lias is marked by the small outlier on the summit of Berrow Hill . . . . . Here only the basement-beds of the Lower Lias are found, above the Rhætic Beds, and they have been quarried for lime-burning.' ('The Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iii, 1893, p. 146.)

I am not aware that the *Pteria (Avicula)-contorta* Zone has been exposed on this hill, and this fact, combined with the interest which would attach to its investigation with a view to seeing whether or not its component beds were modified by proximity to the ancient coast-line (formed mainly of Malvernian aplite and diorite), induced me to make some excavations.

A preliminary survey, carried out in company with Dr. William Washbourn, of Gloucester, had suggested that this would not be an altogether easy task: apart from quarrying-operations, which had greatly disturbed the ground and rendered it difficult to discover virgin soil, the outcrop of the Rhætic Beds was much obscured by woods.

The place finally decided upon for the excavations was in the wheel-track leading from the limekiln to the quarries, and in them most of the following section was exposed:—

		<i>Thickness in feet inches.</i>			
LOWER LIAS. ( <i>Ostrea</i> -Beds.)	Subsoil, with a few quartzite-pebbles	1	2		
	1. Limestone, in several layers, bluish-grey . . . . . at least	1	0		
	2. Marl, bluish-grey, with occasional thin layers of yellowish-brown limestone near the base and one near the centre . . . . .	1	5	<i>Ostrea liassica.</i>	
	3. Limestone, bluish - grey, in several layers . . . . .	0	8	<i>Ostrea liassica, Modiola minima.</i>	

<sup>1</sup> Proc. Cottesw. Nat. F.-C. vol. xv (1905) pp. 93-100.

		Thickness in feet inches.		
LOWER LIAS (continued). ( <i>Ostrea</i> -Beds.)	4. Marl, bluish-grey .....	0	2	{ <i>Ostrea liassica</i> , <i>Modiola minima</i> , <i>Lima gigantea</i> , <i>Paralleodon hettangiensis</i> , <i>Pleuro-myia</i> ; radiolae of <i>Pseudodiadema</i> .
	5. Limestone, bluish-grey: 2 to 5 inches.	0	3	
	6. Marl, blue and yellowish-brown	0	2	
	7. Dark limestone.....	0	2½	{ <i>Ostrea liassica</i> .
	8. Marl, blue and yellowish .....	0	2½	
	9. Dark limestone.....	0	5	{ <i>Ostrea liassica</i> , <i>Modiola minima</i> .
	10. Shale, brown and grey .....	0	5	
	11. Hard, dark limestone .....	0	3	{ <i>Modiola minima</i> , <i>Ostrea liassica</i> .
	12. Marl ... ..	0	2	
	13. Limestone .....	0	2	
	[Gap, but not more than 2 feet.]			
UPPER RHÆTIC.	{ Marls, bluish-grey and pale-yellow, with an indurated band near the top .....			
	5 a. Shales, black, clayey.....	about	9	0
	5 b. Limestone, arenaceous, rust-coloured .....	about	1	0
	6. Shales, black, imperfectly laminated		0	0½
	7. Limestone, grey, arenaceous, weathering brown .....		0	0½
	8 a. Shales, black, tough, laminated...		3	11
	8 b. Shales, grey and yellow, clayey...		1	5
	9. Sandstone, white, micaceous.....		0	0½
	10. Shale, black .....		0	6
	11. Sandstone, white, micaceous .....		0	0½
	12. Shale, grey, clayey .....		1	0
	13. Sandstone, white, micaceous .....		0	0½
KEUPER.	{ Clay and green marl resting upon a yellowish-brown Green deposit .....			
	Marls. { Red marl .....		0	3
	Greenish marls .....	about	11	0
II. Red Marls.				

The Lower *Pecten*-Bed, usually in this county and Gloucestershire a well-developed limestone-bed, is here only half-an-inch thick. The Upper *Pecten*-Bed (5 b) is also feebly represented, but it contained a plicated *Ostrea* (fragments), possibly the precursor of the *Alectryonia* of the Inferior Oolite, which may be tentatively compared with Charles Moore's *Ostrea fimbriata*.<sup>1</sup>

The superincumbent shales are dark and marly at the base, but become paler above and more calcareous. In default of fossils, an arbitrary line of division must be drawn between the two stages of the Rhætic Series.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xvii (1861) p. 501 & pl. xvi, fig. 24.



Despite the fact that several excavations were made in the Upper Rhætic, the only information which could be obtained is that given in the record of the section. A creamy-yellow indurated layer near the top resembled a certain variety of the *Estheria*-Bed, but neither *Estheria* nor *Lycopodites* could be detected in it.

There are two small quarries at present open on the hill, but water continually stands in the bottom. Details of the beds which could be examined are given in the section. From the fields between the kiln and the quarries most of the limestone has been removed.

It is fortunate that it was possible to obtain exact measurements of the component beds of the Lower Rhætic Stage. Several points will be at once commented upon: (1) the extreme tenuity of the *Pteria* (*Avicula*)-*contorta* Zone and of the subjacent 'Tea-Green Marls'; (2) the absence of a layer worthy of the name of 'Bone-Bed,' and the feeble development of hard layers; and (3) the scarcity of Rhætic lamellibranchs.

The nearest locality to Berrow Hill where the whole of the Rhætic Series may be studied is at Wainode Cliff.<sup>1</sup> There the sequence of deposits is (in descending order) as follows:—

		Thickness in feet inches.	
UPPER RHÆTIC.	1. 'Insect-Limestone' .....	0	5
	2. Shales, weathering into a marly clay .....	5	2
	3. <i>Estheria</i> -Bed .....	0	6
	4. Shales, marly .....	6	0
	5 a. Shales, black .....	3	0
	5 b. Upper <i>Pecten</i> -Bed .....	0	1
	6. Shale, black .....	0	10
	7. Lower <i>Pecten</i> -Bed .....	0	3
	8. Shales, black .....	5	4
LOWER RHÆTIC.	9. Sandstone, intermittent .....	0	1
	10. Shale, black .....	0	6
	11. Sandstone .....	0	1
	12. Shale, black .....	1	0
	13. Sandstone .....	0	2½
	14. Shale, black .....	1	0
	15. Bone-Bed .....	0	3
UPPER KEUPER.	16. Shales, black .....	2	0
	I. 'Tea-Green Marls' .....	23	0
	II. Red Marls: seen .....	75	0

There is no doubt that the bed numbered 7 in the Berrow-Hill section corresponds to the similarly-notated stratum at Wainode Cliff; and it will be observed how closely the several beds below that horizon at the former locality correspond to similarly-notated deposits at the latter. But, compared with Wainode Cliff, the sequence of deposits at Berrow Hill is not complete: rock, at least 3¼ feet thick, is missing, because at the latter locality Bed 13 rests directly, with perfect parallelism so far as can be seen, but non-sequentially, upon the 'Tea-Green Marls.'

<sup>1</sup> Proc. Cottesw. Nat. F.-C. vol. xiv (1903) table i, facing p. 174.

There certainly seems to be some overlapping of the 'Tea-Green Marls' by the *Pteria (Avicula)-contorta* Shales here. When my paper on the Rhætic of Monmouthshire was read, Mr. Strahan was unable to agree with me regarding this matter,<sup>1</sup> but it appears difficult to explain otherwise the phenomena observed here and elsewhere; and I would also draw attention to remarks by Moore<sup>2</sup> and Brodie,<sup>3</sup> geologists who were well acquainted with the deposits under consideration.

I am indebted to Mr. H. A. Badham, of Tewkesbury, for obtaining the required permission to make the excavations, and to Mr. E. Talbot Paris for much assistance during the investigations.

#### DISCUSSION ON THE TWO FOREGOING PAPERS.

Mr. STRAHAN said that much was added by these papers to what had been done by previous authors. The existence of an outlier of Lias about which he had been in doubt was now proved, and *Ostrea Bristovi* had been obtained *in situ*. He was unable, however, to see the advisability of introducing the name 'Sully Beds.' It was doubtful what Etheridge had meant by his 'Grey Marls,' and the Author had had to rely upon a biographical notice for an interpretation. Neither the downward nor the lateral extension of the 'Sully Beds' could be defined. The fact that they contained an oyster which did not range up into the *Avicula-contorta* Zone was hardly evidence that they belonged to that zone. Nevertheless, the oyster indicated one of the first stages in the invasion of the area by the sea, and corroborated the view that, for a time, Keuper and Rhætic conditions alternated. The facts scarcely supported the theory that the 'Sully Beds' had been deposited in a lake surviving from Keuper times. The changing of the generic name of *Avicula contorta*, except under the stress of absolute necessity, was greatly to be deprecated.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lxi (1905) p. 384.

<sup>2</sup> *Ibid.* vol. xxiii (1867) p. 468.

<sup>3</sup> *Ibid.* vol. xlii (1886) pp. 273, 275.

20. *The CAUSES of VARIEGATION in KEUPER MARLS and in OTHER CALCAREOUS ROCKS.* By GERALD TATTERSALL MOODY, D.Sc., F.C.S. (Communicated by Prof. W. W. WATTS, M.A., M.Sc., F.R.S., Sec.G.S. Read June 21st, 1905.)

It has long been known that the colouring of stratified rocks is chiefly due to the presence of compounds of iron, although the conditions under which deposition of iron has taken place have not been fully determined. The occurrence of red and green masses of rock in juxtaposition, such as is observed at the junction of the Tea-Green and Red Marls of the Keuper, has given rise to speculation regarding the origin of variegation, but no hypothesis affording a satisfactory explanation of the chemical changes which must accompany such phenomena has been hitherto advanced.

It is generally taken for granted that the red colour of a variegated rock is determined by the presence of ferric oxide, while the green colour is attributed to iron in the ferrous state; and the suggestion has been made that the condition of the iron in the distinct parts of a variegated rock may, in some cases, be dependent on the relative amount of calcium-carbonate present. As far back as 1868, George Maw<sup>1</sup> called attention to the fact that many non-calcareous rocks are red in colour, and he advanced the opinion that the lighter-coloured bands in variegated rocks have been formed from the red or brown rock by addition of calcareous matter from without. This view, that the green portion has been derived from the red portion, appears to be generally accepted by geologists at the present time; and so it seems desirable to quote at length the concluding paragraph of that section of Maw's communication which deals especially with the discoloration of red rocks by lime and magnesia, and runs as follows:—

'Although an increase, from extraneous sources, of the calcareous element in any red bed seems to induce bleaching and discoloration, it does not bear a perfectly-regular ratio to the proportion of lime present, as discoloration has taken place in some red beds connected with the infiltration of a less amount of carbonate of lime than that originally present in others that have not been so changed, and a blood-red colour pervades the base of the Chalk at Hunstanton. It may, however, be generally stated that a bright-red colour is a character of non-calcareous strata, and dun-colour, or grey, of calcareous beds, quite irrespectively of the amount of iron present.' (*Op. cit.* p. 386.)

On reference to the published analyses of red rocks and of their so-called 'bleached' or discoloured parts, it is seen that the lighter-coloured portion usually contains a percentage of iron considerably smaller than the adjacent red-coloured portion. On the other hand, the aggregate percentage of calcium-carbonate and magnesium-

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxiv (1868) pp. 351 *et seqq.*

carbonate expressed in equivalents is generally shown to be higher in the light-coloured portion than in the red mass. It would therefore appear that if the view expressed by Maw (*loc. cit.*) and H. G. Madan,<sup>1</sup> that the light-coloured rock is formed by bleaching or reduction of the iron in the red rock, be correct, such reduction must have been accompanied by the carrying-away from the red rock of a considerable part of its iron, and by the introduction of calcium-carbonate and magnesium-carbonate from without. In the case of the Keuper and other variegated marls, this loss of iron is difficult to understand, and appears on chemical grounds highly improbable, owing to the inhibiting influence of the surrounding calcium-carbonate and magnesium-carbonate on the solubility of ferric oxide. To this protective action of calcium-carbonate and magnesium-carbonate reference is made later (p. 434).

In order to remove any possible doubts regarding the actual composition of the adjacent portions of variegated rocks, it was decided to submit typical examples to careful analysis. Through the kindness of Prof. H. E. Armstrong, Dr. C. G. Cullis, and Mr. L. Richardson, I have been supplied with a large number of specimens of variegated Keuper Marl. Most of these come from the Wainlode-Cliff section, on the left bank of the Severn, between Gloucester and Tewkesbury, where Keuper Marls are exposed for a thickness of 98 feet, 75 feet of which is red marl variegated throughout. Light greenish-grey marls, weathering bluish-green and white, cover the variegated marl; and it is interesting to note that these are in places coloured yellow, through the downward passage of water carrying iron in solution. Other specimens came from Aust Cliff, near Bristol, and from Seaton (South Devon).

Each of the specimens examined showed the green and the red marl in juxtaposition, and presented an appearance which clearly indicated that the colour-change was caused by infiltration, though no evidence was afforded as to whether the alteration was from green to red by upward percolation, or from red to green by downward percolation. The texture of the red and the green parts was somewhat similar throughout, although the red mass appeared in some specimens to be a little less coherent than the green. The greater capillarity of the red part was subsequently made evident, by the fact that it was found to hold a larger percentage of moisture than the green part. Each specimen was broken into pieces weighing from 2 to 5 grammes; and the pieces were subsequently sorted, so as to separate the green and the red portions from each other and from the still variegated portions.<sup>2</sup> The red and green portions were then separately ground to fine powders, and passed through a fine muslin-sieve.

<sup>1</sup> Proc. Cottesw. Nat. F.-C. vol. xiv (1903) p. 132.

<sup>2</sup> However carefully this separation was conducted, the powdered green portions always contained some red particles, and the powdered red rock some green particles.

The following are the numbers obtained in the course of the analysis:—

## MARLS FROM WAINLODE CLIFF.

	No. 1.		No. 2.		No. 3.	
	<i>Green part.</i>	<i>Red part.</i>	<i>Green part.</i>	<i>Red part.</i>	<i>Green part.</i>	<i>Red part.</i>
Fe <sub>2</sub> O <sub>3</sub> .....	1.12	3.12	0.87	3.80	0.92	3.94
FeO .....	1.73	1.65	0.96	0.91	1.62	1.03
CaO .....	5.31	4.73	7.37	5.18	6.10	4.21
MgO .....	4.90	3.81	6.10	5.42	4.30	3.44
CO <sub>2</sub> .....	10.16	8.10	13.01	10.21	11.60	8.79
Water lost at 100° Centigr. ....	3.80	4.22	3.01	3.72	3.35	4.16
Carbon existing as organic matter..	0.174	0.128	0.092	0.106	...	...
SiO <sub>2</sub> .....	50.37	49.67	50.84	50.91	48.91	48.22
Al <sub>2</sub> O <sub>3</sub> .....	14.78	14.16	13.12	12.98	15.15	16.40
TiO <sub>2</sub> .....	0.57	0.62	0.42	0.33	...	...
SO <sub>3</sub> .....	traces	traces	traces	traces	traces	traces
P <sub>2</sub> O <sub>5</sub> .....	only.	only.	only.	only.	only.	only.
Cl <sub>2</sub> .....	only.	only.	only.	only.	only.	only.
Alkalies, combined water, and undetermined .....	7.086	9.792	4.208	6.434	8.05	9.81
	<u>100.000</u>	<u>100.000</u>	<u>100.000</u>	<u>100.000</u>	<u>100.00</u>	<u>100.00</u>

	No. 4.		No. 5.		No. 6.	
	<i>Green part.</i>	<i>Red part.</i>	<i>Green part.</i>	<i>Red part.</i>	<i>Green part.</i>	<i>Red part.</i>
Fe <sub>2</sub> O <sub>3</sub> .....	0.87	3.39	0.66	3.12	1.04	3.14
FeO .....	1.12	0.97	0.92	0.87	1.64	1.45
CaO .....	7.39	6.12	4.17	3.91	4.70	4.85
MgO .....	5.44	4.68	3.60	2.88	3.31	3.19
CO <sub>2</sub> .....	12.30	11.10	6.07	5.93	...	...
Water lost at 100° Centigr. ....	3.12	4.33	2.71	3.04	3.57	3.48
Undetermined .....	69.76	69.41	81.87	80.25	85.74	83.89
	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>

## KEUPER MARL FROM SEATON (SOUTH DEVON).

	<i>Green stratum.</i>	<i>Red stratum.</i>	<i>Hard green band from red stratum.</i>
Fe <sub>2</sub> O <sub>3</sub> .....	0.85	3.66	0.61
FeO .....	1.14	1.16	0.83
CaO .....	13.31	5.74	16.77
MgO .....	2.10	0.73	1.90
CO <sub>2</sub> .....	12.12	5.31	15.17
Water lost at 100° Centigr. ....	2.71	4.04	0.87
SiO <sub>2</sub> .....	45.46	52.11	...
Al <sub>2</sub> O <sub>3</sub> .....	14.40	18.07	...
Undetermined.....	7.91	9.18	63.85
	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>

## KEUPER MARL FROM AUST CLIFF.

	<i>Green portion.</i>	<i>Red portion.</i>
Fe <sub>2</sub> O <sub>3</sub> .....	0.87	3.20
FeO .....	1.43	1.12
CaO .....	7.44	6.13
MgO .....	1.26	0.90
CO <sub>2</sub> .....	7.46	6.23
Water lost at 100° Centigr.	4.31	4.96
SiO <sub>2</sub> .....	56.46	55.08
Al <sub>2</sub> O <sub>3</sub> .....	13.52	14.16
Undetermined .....	7.25	8.22
	<u>100.00</u>	<u>100.00</u>

These analytical results place beyond doubt the fact that the red portion of a variegated rock contains a higher percentage of iron and lower percentages of calcium-carbonate and magnesium-carbonate than the green portion; and they are in agreement with the observation of Maw that red strata are usually less calcareous than adjacent green strata.

Two hypotheses, in explanation of the difference in composition of the parts of variegated rock caused by infiltration, are possible. The first is that the green rock may have been formed by the removal of ferric oxide from, and by the addition of lime and magnesia to, the rock. The second is that the green rock may have been converted into the red rock by the addition of ferric oxide, and by loss of lime and magnesia.

The first hypothesis was advanced by Maw, and it is necessary to consider if, and to what extent, such an exchange of lime and magnesia for ferric oxide in the red rock is possible. The removal of ferric oxide from a red marl necessarily involves previous dissolution of the iron. The dissolution might be brought about, either by exchange of the basic portion of some soluble salt for ferric oxide, or by direct dissolution of the iron-oxide in acid. Experiments were made with the object of removing the iron either partly or entirely from the red marl, by passing through it solutions of calcium- and magnesium-salts, including the sulphates, chlorides, and bicarbonates. Calcium-bicarbonate and magnesium-bicarbonate were prepared by aerating saturated lime-water and magnesia suspended in water, respectively, in a 'sparklet'-siphon. The resulting clear solutions were subsequently forced by their own pressure through glass Soxhlet tubes containing the powdered marl. In all these experiments negative results were obtained, not a trace of iron going into solution.

The action of acids on the red marl was next studied. The marl in fine powder was placed in beakers, made into a stiff paste with water; and solutions of acid of approximately-normal strength were added drop by drop, with constant stirring. It was found in every experiment that no iron passed into solution, so long as any of the magnesium-carbonate or calcium-carbonate of the marl remained undissolved. The addition of acid without stirring, leading to

momentary excess of acid in one part of the beaker, might induce temporary dissolution of the iron, but on stirring the sludge the whole of the iron was immediately reprecipitated in the form of oxide. As soon as the complete decomposition of the calcium-carbonate and magnesium-carbonate was effected, the paste on further addition of acid permanently assumed the colour of iron, and gave the reactions characteristic of it. Precisely-similar results were obtained on treating with acids intimate mixtures of ferric oxide and chalk, of ferric oxide and magnesium-carbonate, and of ferric oxide and dolomite.

It must, therefore, be accepted that the removal of iron existing as ferric oxide from a homogeneous rock-mass is inhibited, if either calcium-carbonate or magnesium-carbonate, or both of these substances, be present; and it follows that the variegation of marls is not to be explained by the assumption that bleaching of the red rock has occurred through reduction of ferric oxide and loss of iron.

The adjacent portions of red and green rock, while showing a great difference in total iron, contain very nearly the same percentage of combined ferrous oxide. This agreement in ferrous-oxide content can scarcely be accidental, and is in itself almost suggestive that the red rock has been produced from the green by the deposition within its pores of finely-divided ferric oxide. It is noteworthy that, on natural weathering, the green marl does not turn brown, but assumes a bluish-grey colour. Nor is any marked change in colour produced on exposing the finely-divided marl, kept moist, to the acid fumes of a laboratory for several months. There is no indication in either case cited, of the production of ferric oxide, such as would be expected if the green colouring-matter had been formed by the reduction of ferric oxide in the red marl. Such reduction would give rise to a ferrous compound, itself very sensitive to the influence of atmospheric oxygen; whereas the colour of the green marl is, under the conditions named, extraordinarily stable. The ferrous compound in the green marl remains undissolved after long-continued contact with either a solution of carbon-dioxide, which dissolves ferrous carbonate, or a large excess of very dilute hydrochloric acid; the rock contains practically no pyrites, and it seems most probable that the colour of the marl is due to ferrous silicate, or to some double silicate containing ferrous oxide. Confirmation of this view is afforded by the fact that, in determining ferrous iron in the marl, maximum and concordant results were obtained only by a method involving rapid dissolution of the rock in a mixture of sulphuric and hydrofluoric acids.

Experiments were next made with the object of determining the conditions under which the green marl could be converted into red marl. Such a change involves the addition of ferric oxide, which might be deposited from solutions of iron existing in the earth's crust. In some parts, such as the Wealden area in the Isle of

Wight, there are at the present time enormous volumes of subterranean chalybeate waters which contain either ferrous sulphate or ferrous bicarbonate, but usually the latter.

An artificial chalybeate water-ferrous bicarbonate solution was prepared by placing soft iron-wire and water in a 'sparklet'-siphon and then aerating with a 'sparklet.' After twelve hours the solution gave all the characteristic reactions of a strong natural chalybeate water. It had an inky taste, and, when boiled, yielded a greenish-white precipitate of ferrous carbonate which rapidly turned brown on exposure to air. Solutions of iron prepared in this way contained as much as 0.3 gramme of iron per litre.

The artificial chalybeate water, when forced by pressure of carbonic-acid gas through a mixture of sand and chalk, was found to give up the whole of its iron, calcium-bicarbonate passing into solution. The substitution of magnesite, dolomite, and green marl for the sand and chalk led to precisely-similar results, the effluent water being free from iron, but containing calcium- or magnesium-bicarbonate. On exposure to air, the masses holding the precipitated iron assumed a red or brown colour.

In the case of a rock containing both magnesium-carbonate and calcium-carbonate, it was found that chalybeate water most readily exchanged iron for magnesium. When the water was passed through a long column of powdered dolomite, the effluent at first contained only magnesium-bicarbonate; and it was not until a relatively-large volume of the water had passed through the rock, that calcium-bicarbonate could be detected in the solution.

It appeared of interest to convert part of the green portion of some variegated marl artificially into red marl, and to compare the colour and composition with the naturally-occurring red part. To this end a stream of chalybeate water was passed through a finely-divided green portion of marl for several hours. The product was then spread on a plate and dried in an air-oven, when it was found not only to match nearly in colour the naturally-red part, but also to resemble it closely in chemical composition, as shown by the following numbers:—

	NATURAL.		ARTIFICIAL.
	<i>Green marl.</i>	<i>Red marl.</i>	<i>Red marl.</i>
Fe <sub>2</sub> O <sub>3</sub> .....	0.87	3.80	4.96
FeO .....	0.96	0.91	0.61
CaO .....	7.37	5.13	4.92
MgO .....	6.10	5.42	4.77
CO <sub>2</sub> .....	13.01	10.21	9.61
Undetermined .....	71.69	74.48	75.13
	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>

The ease with which iron is deposited from solution, in exchange for calcium and magnesium, affords strong evidence in favour of the view that variegation in rocks has in many cases resulted primarily from the passage of chalybeate water through



calcareous strata. Subsequently, when conditions were favourable, owing to subsidence of water, air has been introduced, and the ferrous carbonate has been converted into ferric oxide. That the Keuper Marls have been variegated in this way admits of no doubt. The pale blotches, stringers, and spherical masses occurring in the red marl, represent not parts where reduction of ferric oxide has taken place, but portions of the rock-mass which at the time of percolation were hard, crystalline, and impervious to the chalybeate solution. As bearing on this, it is noteworthy that both the red and the green parts of the variegated marl contain practically the same amount of carbon present as organic matter. This even distribution of organic carbon through the variegated rock is scarcely to be interpreted in favour of the view that the green marl has been derived from the red marl, by reduction of ferric oxide owing to percolation of water containing organic matter in solution.<sup>1</sup>

The continuous passage of chalybeate water through strata containing calcium and magnesium would, in time, rob them entirely of these constituents; and, therefore, it may be properly inferred that rocks which are saturated with and are exuding chalybeate water are devoid of calcareous matter.

The even distribution of ferric oxide in the Triassic rocks of England makes it probable that the colour of the red sandstones, as well as of the red marls, has been caused by the action of chalybeate water, which it must be assumed permeated the whole of the New Red Sandstone and part of the overlying marls. Since the pale blotches in the red Bunter Sandstone contain only about one-third of the iron present in an equal mass of the red matrix, it is likely that careful investigation will show that the red matrix contains ferrous oxide equivalent to the whole of the iron in the pale blotches; and should this be the case, additional evidence of the deposition of ferric oxide from external sources will be afforded.

To what extent the colour of other red rocks, such as the Red Chalk of Hunstanton, is to be attributed to the action of chalybeate waters, is an interesting subject for enquiry; but it must be accepted that the ease with which ferrous carbonate is precipitated from solution, and converted into ferric oxide, makes it highly probable that chalybeate waters have played a very important part in the colouring of rocks.

#### DISCUSSION.

The PRESIDENT congratulated the Author in that he was able, by the aid of chemistry, to throw light upon the origin of rocks concerning which palæontology was almost silent. It would be interesting to know how the water was introduced which produced a change in a great thickness of rocks now coloured red, leaving a thin mass of Tea-Green Marls above. He hoped that the Author would investigate

<sup>1</sup> See H. G. Madan, *Proc. Cottesw. Nat. F.-C.* vol. xiv (1901-03) p. 132.

other cases, such as the green spots in the red and purple Cambrian slates of North Wales, and the curious concentric shells of alternating red and green colour in the Moughton Whetstones of the West Riding of Yorkshire.

Prof. H. E. ARMSTRONG spoke of the value of the paper, as showing how numerous were the points of contact between geology and the other sciences. The explanation advanced by the Author that the red coloration of many rocks was due to the displacement of magnesium and calcium by ferrous iron, which subsequently became oxidized, was both rational and reasonable; but it remained to ascertain what were the physical peculiarities which affected the percolation of the clay by chalybeate waters. It was not merely a question of this or that distinct layer being penetrated: at Seaton, for example, little blue masses occur interspersed throughout the red clay in the most irregular manner possible. The speaker also referred to the interest attaching to the determination of the nature of the mineral which was the essential constituent of the blue clay.

Prof. SEELEY said that the alternation of red and green clays and marls, though not limited to freshwater deposits, was characteristic of the Headon Beds, the Woolwich and Reading Beds, and especially of the Keuper Marls, which were presumably freshwater deposits. In no case did these beds show evidences of infiltration. In the Reading Beds the clays in several localities showed current-bedding, with alternations of lamination of scarlet clays with green clays. This was some evidence that the clays were coloured when originally deposited. When the scarlet beds were followed for some distance they became plum-coloured, and the green beds became grey, and more or less mottled. The only condition of alternation which would affect the oxidation of iron in the sediments of all deposits of all ages, was the alternation of the seasons; and he suggested that the green marls were formed in cold winter-seasons, and the thicker red clays in warmer wet seasons.

Dr. J. W. EVANS referred to the replacement of carbonate of lime by iron-ore in some of the Jurassic limestones, as a parallel to the changes shown by the Author to have taken place in the variegated marls. In the latter case, he suggested that the chalybeate waters had ascended from the red Triassic sandstones. He thought that, in some instances, the occurrence of red bands or patches might be determined by the previous distribution of carbonate of lime or magnesia which caused the deposition of iron. He mentioned that the 'silver-amber' phlogopite-mica of Brazil showed brown patches in the neighbourhood of cracks, and that these on analysis proved to contain more iron and water and less magnesia than the unaltered portions of the mica.

Mr. O. A. SHRUBSOLE remarked that he had observed instances, in the Grès de May of Normandy, where a greenish quartzite had been partly stained red by infiltration. He agreed, however, that the explanation hardly covered other cases, such as the mottled clay of the Reading Beds.

Mr. J. V. ELSDEN asked whether the Author's attention had been

drawn to the nature of the colouring-matter in the pale-green (greenish-white) sandstones of Carboniferous age occurring in Scotland. These occasionally exhibited the defect of staining to a red colour along the mortar-joints when used as building-material. The action often took place with great rapidity. Some specimens which came under the speaker's notice were conspicuously mottled in a few days, after contact with calcium-hydrate solution in the form of slaked lime.

The AUTHOR, in reply, said that in the Pylle-Hill section, which had been described by the late Edward Wilson, the Tea-Green Marl passed insensibly into the variegated marl lying beneath, and was apparently identical with the green portions of the variegated rock. While it was true that the Tea-Green Marl was a relatively-thin deposit, and that the variegated marls and Triassic Sandstone formed in the aggregate strata of enormous thickness, it was not necessary in consequence to assume that the former had undergone colour-change. The percolation of chalybeate water from below into a rock originally all green seemed equally or more probable. At the present time, an inexhaustible volume of chalybeate water existed in the Wealden area in the Isle of Wight, and this water was being brought to the surface and used in the power-house of the Electric-Light Works between Sandown and Shanklin. In earlier geological periods, chalybeate waters were probably more common than they are now. It need not be assumed that the chalybeate water-level coincided with the uppermost red rocks, for the capillarity of the mass would allow of an easy upward passage of the water. He differed from Prof. Seeley in thinking that the appearance of the Keuper Marls was entirely in favour of infiltration, and in this connection might point out that the upper portions of the Tea-Green Marl are undergoing colour-change through the percolation of water carrying iron from above.

With regard to Prof. Armstrong's remarks, he felt that he was under a far greater obligation to that gentleman than was incurred in the mere receiving of specimens. He had had the privilege of discussing with him the various points which arose during the course of the investigation, and he was deeply sensible of the help which such an association had afforded.

21. *On NEW OOLITIC STRATA in OXFORDSHIRE.* By EDWIN A. WALFORD, F.G.S. (Read June 21st, 1905.)

[Abstract.]

THE divisions of the Inferior Oolite of North-West Oxfordshire are described, and a quarry on the border of the county cited where the Cotteswold facies dies out in the '*Parkinsoni*'-stage. A higher division of the same stage (the *Trigonia-signata* Beds) of Northamptonshire type is shown to sweep over the North-Eastern Cotteswold region. The siliceo-calcareous beds (Chipping-Norton Limestone) cover the countryside which gives them their name, and are about 30 feet thick. Fossiliferous strata, separated from the Chipping-Norton Limestone by a bed with vertical markings and a black clay-band, indicative of much 'inter-waste' of these and other beds, are described. They are shown to be similar to the Lincolnshire (Ponton) strata described by Morris, Judd, and Woodward. A new term is proposed for these beds, which are characterized by the presence of the shell *Næra*, from the *Perna*-Marls above the black clays to a higher series of black-and-green clays underlying the Stonesfield Slate. These beds and the Chipping-Norton Limestones are classed with the sub-Bathonian.

The beds equivalent to those of Oxfordshire have, in Lincolnshire and Northamptonshire, been known in part as Upper Estuarine. In the 20 feet of Oxfordshire strata the 150 feet of the Lincolnshire Limestone and the Upper Estuarine of the north-eastern counties appear to be represented. The Author expresses the hope that his work may help towards the discrimination of the two kinds of deposit known as Lincolnshire Limestones, inasmuch as the fossils characterizing each local (Oxfordshire) stratum have been collected from the beds *in situ*. Lists of fossils are given.

22. *The BLEA WYKE BEDS and the DOGGER in NORTH-EAST YORKSHIRE.* By ROBERT HERON RASTALL, B.A., F.G.S., Christ's College, Cambridge. (Read April 19th, 1905.)

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## I. INTRODUCTION.

THE exact stratigraphical position of the Blea Wyke Beds and their relations to the beds above and below them have given rise to a great deal of discussion, but no very satisfactory conclusion seems to have been reached by any of the writers on the question.

Many attempts have been made to assign these beds to the Lias or to the Inferior Oolite, but hitherto there has always been some objection to drawing a hard-and-fast line at any particular horizon; and in these days, when less importance is attached to arbitrary divisions of geological time, and more to broad questions of physical geography, it seems worth while to study the question afresh from a more modern standpoint.

These beds are also noteworthy for another reason, because a study of them seems to throw some light on the history of the Peak Fault, perhaps the greatest and most important dislocation in North-East Yorkshire.

Before beginning the detailed study of the Blea Wyke Beds, it will be necessary to say a few words concerning the general structure of the district in which they are developed.

The southernmost exposure of the Lias on the Yorkshire coast is in the cliffs below what was formerly known as Peak, but now called Ravenscar.

At this point the beds have a rather steep dip to the south, and by proceeding northwards from Staintondale, we pass in succession over a fine series of Oolitic and Liassic strata. The Oolites form the cliffs as far north as Blea Wyke, a small point and bay almost directly below Ravenscar Railway-station: here the top of the Upper Lias appears, and can be easily followed in the cliffs for a mile or so to the north-west, where it is cut off by the Peak Fault. This fault has a throw of some 400 feet, and brings up Middle Lias against the base of the Lower Estuarine Series.

Within this space of a mile are to be seen a set of strata intermediate between the Lias and Oolites, such as are known nowhere else in Yorkshire. When we reach the next exposure, less than a mile to the north-west, the character of the section has entirely

changed, and some 150 feet of the cliff-section seems to be unrepresented. Over the rest of the Jurassic area, to the north and west, this second type of junction between the Lias and Oolites alone occurs; and it is the object of the present paper to attempt to offer an explanation of this state of things.

Before discussing this question it will be necessary to describe, somewhat in detail, the section at Blea Wyke, and some of the more northerly and westerly sections where the junction is visible. Fortunately such sections are numerous, as these beds are always well displayed in the old Alum-Shale quarries which are so abundant in this neighbourhood. The Alum-Shale is, practically, the *Ammonites-communis* and *bifrons*-zone, and no higher zone is developed to any appreciable extent in these quarries. Directly upon it rest what appear to be the basement-beds of the Oolites, commonly known as the Dogger; and to this our attention will be directed, in the endeavour to discover elsewhere representatives of the passage-beds of Blea Wyke.

## II. THE TYPICAL SECTION: BLEA WYKE POINT.

Immediately below Ravenscar Railway-station the cliff is 600 feet high, and shows a very fine section of the estuarine development of the Middle Jurassic, from the Moor Grit downwards: this series is here unusually thick, measuring about 630 feet, instead of some 400 feet as usual.

The Blea Wyke Beds and the overlying Dogger form a small headland, Blea Wyke Point, while the softer *Striatulus*-Shales have been excavated into a small wyke or bay, to the west of the point. This bay and point are very easily reached by a path down the cliff immediately opposite the station, and this is much the best locality to study these beds.

At the point the 'Dogger' and Yellow Beds form the lowest part of the cliff, while the underlying beds form flat scaurs covered at high tide.

The detailed section here is as follows:—

		Thickness in feet.
DOGGER.	Ferruginous sandstone, with scattered pebbles .....	10
	' <i>Nerinea</i> -Bed': band of shells preserved in iron-oxide .....	1½
YELLOW BEDS.	Greenish-yellow sandstone, with bands of pebbles .....	25
	Brown shaly bed .....	1
	Brown sandstone, full of <i>Terebratula trilineata</i> .....	2
	Yellow sandstone, with a band of belemnites and pebbles at its base .....	1
	Yellow ferruginous sandstone .....	2
	Very soft yellow sandstone .....	1
	Soft yellow ferruginous sandstone, with iron knobs and concretions; in the lower part are very numerous specimens of <i>Avicula</i> , with <i>Serpula</i> , <i>Pecten</i> , <i>Rhynchonella</i> , <i>Mytilus</i> . .....	20
	Soft rotten band .....	1

[Blea Wyke Section (*continued*).]

		Thickness in feet.
SERPULA-BEDS.	Grey sandstone, weathering into nodules .....	4
	Brown ferruginous band, with a layer of belemnites at its base. ....	1
	Grey, false-bedded, very micaceous sandstone, with a band of <i>Serpula</i> and casts of belemnites at the base .....	5½
LINGULA-BEDS.	Grey sandstone and sandy shale, with fossils in nests, <i>Lingula</i> , etc. ....	25
	Grey shale, with <i>Lingula Beanii</i> , etc. ....	7

Below this comes a thick mass of shale with ironstone-nodules, the *Striatulus*-Shales. Their thickness is doubtful: Tate & Blake say 70 feet, but this is possibly an exaggeration. Farther west this can be seen to rest on Alum-Shale, with *Ammonites communis* and *Leda ovum*.

The classification of these beds adopted in the foregoing section is a slight modification of that proposed by Mr. Fox Strangways in the Survey Memoir.<sup>1</sup> The most important difference is that the base of the Dogger proper has been drawn just below the *Nerinea*-Bed, instead of some 25 feet lower down, as usual. The reason for this will be discussed later.

The base of the Blea Wyke Series is never clearly seen; but it is quite evident that between the undoubted Upper Lias with *Ammonites communis* and *Leda ovum* (the Alum-Shale) and the sandy *Lingula*-Beds there occurs a considerable thickness of shale, lithologically very similar to the Alum-Shale, but containing fossils which belong to a higher horizon: Tate & Blake<sup>2</sup> give the following list of fossils (as quoted by Mr. Fox Strangways):—

*Discina reflexa*.  
*Rhynchonella jurensis* (?).  
*Waldheimia Lycetti*.

*Dentalium elongatum*.  
*Actæon Sedgwicki* var. *pullus*.  
*Cerithium armatum*.

*Avicula inæquivalvis*.  
*Avicula substriata*.  
*Lima toarcensis*.  
*Ostrea subauricularis*.  
*Pecten disciformis*.  
*Pecten pumilus*.  
*Cardium substriatulum*.  
*Gresslya abducta*.  
*Gresslya donaciformis*.  
*Leda æquilatera*.  
*Trigonia literata*.  
*Venus tenuis*.

*Ammonites comensis*.  
*Ammonites compactilis*.  
*Ammonites hircinus*.  
*Ammonites insignis* (?).  
*Ammonites jurensis*.  
*Ammonites lectus*.  
*Ammonites rudis* (?).  
*Ammonites striatulus*.  
*Ammonites variabilis*.  
*Belemnites athleticus*.  
*Belemnites lævis*.

The ammonites show that we have here a representative of the *jurensis*-zone, while the other forms indicate a mixture of Liassic and Oolitic organisms, the former being most abundant. Owing to the poorness of the exposures, I have not attempted to verify the

<sup>1</sup> C. Fox Strangways & G. Barrow, 'The Geology of the Country between Whitby & Scarborough' (Expl. Quarter Sheet 95 N.W.) Mem. Geol. Surv. 1882, p. 26.

<sup>2</sup> 'The Yorkshire Lias' 1876, pp. 190-91; & C. Fox Strangways, 'The Jurassic Rocks of Britain: vol. i—Yorkshire' Mem. Geol. Surv. 1892, p. 136.

foregoing list, but have taken it, as it stands, from the Geological-Survey Memoir. In their original list Tate & Blake gave several more species of ammonites, which are, however, rejected by the officers of the Geological Survey. They seem to be species founded by Simpson on minute variations.

I now proceed to describe the other beds exposed at Blea Wyke, in ascending order:—

### (1) The *Lingula*-Beds.

These beds consist of two parts: (i) some 7 feet of shale at the base, and (ii) above this 25 feet of grey sandstone and sandy shale.

The following species have been found in these beds<sup>1</sup>:—

*Heterocidaris* (*Pseudodiadema*)  
*wickensis*.

*Eryma* (*Glyphæa*) *Birdii*.  
*Glyphæa* sp. cf. *Gl. rostrata*.

*Discina* (*Orbicula*) *reflexa*.  
*Lingula* *Beanii*.  
*Rhynchonella cynocephala*.  
*Terebratula trilineata*.

*Avicula* (*Monotis*) *substriata*.  
*Gervillia Hartmanni*.  
*Pecten demissus*.  
*Pecten Silenus*.  
*Pecten wickensis*.  
*Pinna cuneata*.  
*Cucullæa cancellata*.

*Goniomya angulifera* (?).  
*Gresslya donaciformis*.  
*Gresslya peregrina*.  
*Gresslya Seebachii*.  
*Modiola* (*Mytilus*) *scalprum* (?).  
*Pholadomya fidicula*.  
*Trigonia Leckenbyi*.  
*Venus tenuis*.

*Cerithium quadrilineatum*.  
*Cerithium quinquepunctatum*.

*Ammonites aalensis*.  
*Ammonites comensis*.  
*Belemnites Bucklandi*.  
*Belemnites inornatus*.  
*Belemnites irregularis*.  
*Belemnites Milleri*.

The most important forms here are *Lingula Beanii*, *Rhynchonella cynocephala*, *Terebratula trilineata*, and *Ammonites aalensis*, all of which denote a facies rather Oolitic than Liassic.

This bed forms the lower part of the scaur at Blea Wyke Point, south of the small bay formed by the soft *Striatulus*-Shales.

### (2) The *Serpula*-Beds.

Above this come the *Serpula*-Beds, which are about 10½ feet thick, and are very conspicuous in the cliffs, on account of their very pale colour, nearly white on a weathered surface. The brown band really differs from the rest only in its colour, but it is very persistent.

The fauna of these beds is less abundant than in those below; it is as follows (*teste* C. Fox Strangways, *op. supra cit.* p. 153):—

*Serpula deplexa*.  
*Vermicularia compressa*.  
*Lingula Beanii*.  
*Waldheimia carinata* var. *Blakei*.  
*Pecten intercostatus*.

*Pinna ampla* (?).  
*Cardium striatulum*.  
*Gresslya peregrina*.  
*Dentalium elongatum*.  
*Ammonites aalensis* var. *Moorei*.

<sup>1</sup> C. Fox Strangways, 'The Jurassic Rocks of Britain: vol. i.—Yorkshire' Mem. Geol. Surv. 1892, p. 152.



The foregoing list does not give us much information : *Lingula Beanii* is still found, but in much diminished numbers, and *Ammonites Moorei* can hardly be separated from *A. aalensis*. These beds, therefore, may be regarded as merely a continuation of those below, and by the officers of the Geological Survey both are grouped together as the Grey Beds. This is a purely-lithological division, but it seems to be borne out by the palæontological evidence.

### (3) The Yellow Beds.

The Grey Beds pass up, without any real break, into the Yellow Beds, a thick series of ferruginous sandstones, with occasional shaly bands and numerous lines of black pebbles. It is divided into two parts by a very fossiliferous band, generally known as the *Terebratula*-Bed, about 2 feet thick.

The soft band at the base is not really very different from the sandstone above; but it is always deeply weathered out, and forms a very conspicuous line in the cliffs. The rest of the series, up to the *Terebratula*-Bed, is very uniform, and only varies slightly in colour. The brown shaly bed above the *Terebratula*-Bed always weathers out very deeply and makes, perhaps, the most marked lithological break in the whole series, so much so that it is generally taken as the dividing-line between the Blea Wyke Beds and the Dogger proper. For various reasons, however, I have drawn this line some 25 feet higher up.

The fauna of these Yellow Beds is a rather large one, but the fossils are always so badly preserved that, in many cases, specific determination is almost or quite impossible. They are nearly all in the form of ferruginous casts, in the lower 5 feet or so; above this fossils are rare, until we come to the *Terebratula*-Bed, where the state of preservation is much better, but specimens are difficult to extract. In the published lists of fossils from this horizon there exists a good deal of confusion, as no distinction has in most cases been made between the *Terebratula*-Bed and the 25 feet of yellow sandstone below it. In some cases, to make matters worse, the fauna of these beds is lumped in with that of the *Nerinea*-Bed and the Dogger proper of this and other localities.

From the lower part of the sandstone I have obtained the following fossils :—

*Pentacrinus.*  
*Rhynchonella subtetrahedra.*  
*Avicula inæqualvis.*  
*Avicula substriata.*  
*Pecten barbatus.*  
*Pecten demissus.*  
*Modiola cuneata.*

*Astarte elegans.*  
*Trigonia costata.*  
*Trigonia Ramsayi.*  
*Nerinea cingenda.*  
*Cerithium* sp.  
*Ammonites Moorei.*  
*Ammonites* (a smooth species).

Besides these, there are a few lamellibranchs and other fossils of uncertain position.

The *Terebratula*-Bed consists of 2 feet or so of dark-brown sandstone, full of fossils, which are, however, very difficult to extract in a perfect state. By far the most abundant is *Terebratula trilineata*, but the following are also recorded from this bed<sup>1</sup>:—

*Terebratula submaxillata.*  
*Rhynchonella cynocephala.*

*Gresslya peregrina.*

*Trigonia Ramsayi.*

*Belemnites inornatus.*  
*Belemnites irregularis.*

Above this comes a brown shaly bed, about 1 foot thick, containing very few fossils. I have obtained only an internal cast of an indeterminable *Trigonia*. This bed is noteworthy for the very large amount of mica which it contains. All the beds of the Blea Wyke Series are markedly micaceous, but this is the most conspicuous of all in that respect. The great abundance of detrital mica may possibly throw some light on the source of the material of which these rocks are composed.

This shaly bed is succeeded by some 25 feet of greenish-yellow sandstone, usually classed with the Dogger; but, for reasons which will appear later, I have drawn the base-line of the Dogger at this horizon. Lithologically, this sandstone is very similar to the Yellow Beds below it, and contains abundant pebbles.

Perhaps the most noticeable feature of these Yellow Beds is the occurrence of numerous bands of black nodules or pebbles, which occur at several different horizons, as well as scattered at intervals throughout the whole series. The origin and nature of these pebbles has given rise to much discussion, without any very satisfactory conclusion. It is obvious that many of them are rolled fragments of fossils, and some are clearly recognizable as Liassic ammonites. These pebbles have a very wide distribution, being found at most of the sections where the junction of Lias and Oolite is displayed. They vary considerably in size at different localities, but at Blea Wyke they are generally small, not often exceeding 1 inch in diameter. It is significant that they increase in number towards the top of the passage-beds, in which other indications point to a gradual shallowing of the water, or approach to a shore-line.

#### (4) The Dogger.

The beds which are here taken to be the equivalent of the base-ment-bed of the Oolite, or Dogger, of other sections in the northern part of the district, consist of two parts, thus:—

	<i>Thickness in feet.</i>
Ferruginous sandstone, with scattered pebbles .....	10
The <i>Nerinea</i> -Bed .....	1½

<sup>1</sup> C. Fox Strangways, 'The Jurassic Rocks of Britain: vol. i—Yorkshire Mem. Geol. Surv. 1892, p. 153.

The so-called 'Nerineæ-Bed' is a thin ferruginous band, composed very largely of shells, often broken, and preserved in reddish ferric oxide. The band is accessible only for a short distance, and is not at all conspicuous to the eye. This is the source of most of the fossils in museums which are labelled 'Dogger, Blea Wyke,' 'Inferior Oolite, Peak,' and so on. The fauna is a large one. The following list, taken from Messrs. Fox Strangways & Barrow's Memoir<sup>1</sup> before quoted, is given, for comparison with the fauna of the inland sections:—

*Rhynchonella obsoleta.*  
*Terebratulæ perovalis.*  
*Hinnites velatus.*  
*Gervillia tortuosa.*  
*Pteroperna striata.*  
*Modiola cuneata.*  
*Cucullæa cancellata.*  
*Macrodon hirsonensis.*  
*Trigonia denticulata.*  
*Trigonia V-costata.*  
*Trigonia spinulosa.*  
*Cypricardia acutangula.*  
*Tancredia axiniformis.*  
*Cardium striatulum.*

*Opis Phillipsii.*  
*Astarte elegans.*  
*Ceromya bajociana.*  
*Gresslya adducta.*  
*Natica adducta.*  
*Natica punctura.*  
*Chemnitzia lineata.*  
*Nerineæ cingenda.*  
*Cerithium, 2 spp.*  
*Alaria Phillipsii.*  
*Onustus pyramidatus.*  
*Nerita lævigata.*  
*Trochotoma.*  
*Actæonina.*

This fauna possesses an undoubtedly-Oolitic facies. Unfortunately, ammonites are entirely absent, consequently the exact zonal position of the bed cannot be determined. However, I shall here regard it as the basement-bed of the Oolites of this region, without troubling myself as to its correlation with one or other of the minute subdivisions proposed by Mr. S. S. Buckman and others for the Inferior Oolite of the South-West of England.

Above the *Nerineæ*-Bed come 10 feet or so of yellow ferruginous sandstone, with scattered pebbles. This is undoubtedly the equivalent of the 'Dogger' or 'Top Seam' of the other sections; it weathers out, in a peculiar and very characteristic way, into knobs and concretions of iron-oxide, very like the Lower Greensand of Bedfordshire and Cambridgeshire, as also do the Yellow Beds below. This sandstone seems to be quite unfossiliferous, but very little of it can be reached: the only accessible part extends for a few yards at the southern end of the section, where the lowest division of the cliff dwindles away to nothing and disappears; the southerly dip is here strong, and soon carries the whole series below sea-level. Farther north this division is quite inaccessible.

Above this sandstone comes a thick series of dark shales with beds of sandstone, the typical estuarine development of this part of the Jurassics of Yorkshire. This series is very well displayed in the upper part of the cliffs above Blea Wyke Point. The Estuarine Beds, as a whole, are here perhaps rather more shaly than usual,

<sup>1</sup> 'The Geology of the Country between Whitby & Scarborough' (Expl. Quarter Sheet 95 N.W.) Mem. Geol. Surv. 1882, p. 27.

and plant-remains (probably reeds and water-plants) in an upright position are abundant. They indicate deposition in the muddy estuary of a large river.

The foregoing account applies to the beds as seen in the immediate neighbourhood of Blea Wyke Point, and the thicknesses are measured at that place. The whole series can be very well seen in the cliffs to the north; but the southerly dip soon carries them out of reach, and brings up the Upper Lias to form the base of the cliff. The cliffs here are 600 feet high, and for some distance the lower half, where these beds occur, is nearly vertical, so that they are inaccessible for detailed examination.

About a mile to the north-west of Blea Wyke, and immediately below the Ravenscar Hotel (formerly Peak Hall, or Raven Hall), the whole series is suddenly cut off by the Peak Fault, which brings up sandy Middle Liassic Shale against the lowest beds of the Estuarine Series. It is noticeable that the beds on the east, or downthrow side of the fault, are bent down sharply towards it for a few yards. This seems to indicate that the last movement along this line was in a direction contrary to that of the chief displacement; that is, that the throw was probably once somewhat greater than it is now, and that a reverse movement occurred at a later period.

Immediately to the east of the fault is a fine section displaying the whole of the Blea Wyke Series, as far down as the top of the *Striatulus*-Shales, and overlain as usual by the sandstones, shales, ironstones, and thin coals of the Estuarine Series. The Blea Wyke Beds here are a little thinner than farther east, at least so far as the upper divisions are concerned; but they retain the same characters as before described, including the characteristic irony weathering and bands of pebbles. It is very interesting to note, that for a short distance east of the fault the uppermost bed (the Dogger proper) takes on the peculiar characteristics of the red rock with pebbles and white fragments which I shall have to describe so often later, as the basement-bed of the Oolite in the Peak alum-works and most of the coast and inland sections. The resemblance between parts of the Yellow Beds and the Lower Greensand of Bedfordshire is here more pronounced than even at Blea Wyke.

From this point the contour-lines turn sharply inland, and there are no more exposures for some distance.

### III. THE COAST-SECTIONS.

#### (1) Peak Alum-Works.

The next exposure of the Dogger is in the Peak alum-works, only about half a mile due west of the last; here, however, the section is remarkably different.

Near the middle of this great excavation the following section was measured :—

<i>Thickness in feet inches.</i>		
Shales, with ironstone-doggers, etc.		
Massive, brownish-grey, carbonaceous sandstone ...	4	0
Sandy carbonaceous bed .....	1	0
Very hard ironstone, with white fragments .....	2	0
Ditto, with many black pebbles .....	0	9
Ditto, without pebbles .....	1	6
Bluish shale.....	0	3
Nodular ironstone .....	1	0
Alum-Shale below.		

The lowest band of ironstone is of the ordinary type without pebbles, and probably belongs to the Lias, as also does the 3-inch band of shale, which is not constant. The next three divisions are very similar in character, and differ only in the presence or absence of pebbles. The pebble-band has no definite boundaries, and is not always at exactly the same distance from the base of the bed. The upper division has a peculiar, vertical, columnar jointing, which is not found in the others. The next bed above this is also peculiar: it can only be described as a mixture of fine coal and sand. In the upper sandstone also plant-remains are very abundant, but fragmentary, and I could only identify *Equisetum (columnare?)*. Otherwise the whole series appears to be entirely unfossiliferous.

At the north-western end of this quarry it can be very clearly seen that the Pebble-Bed rests upon an uneven surface, composed of ironstone-nodules, apparently belonging to the Lias.

## (2) Saltwick and Whitby.

About the middle of Saltwick Bay is a very clear exposure of the Dogger, and the following section was measured, just at the top of the lowest grassy slopes which form the greater part of the cliff in this neighbourhood :—

<i>Thickness in feet inches.</i>		
Estuarine Sandstone above.		
Shale .....	15	0
Conglomeratic ironstone, with <i>Lingula Beani</i> .....	3	0
Pebble-Bed .....	0	3
Hard, fine-grained ironstone .....	1	0
Alum-Shale, very ferruginous for 1 foot.		

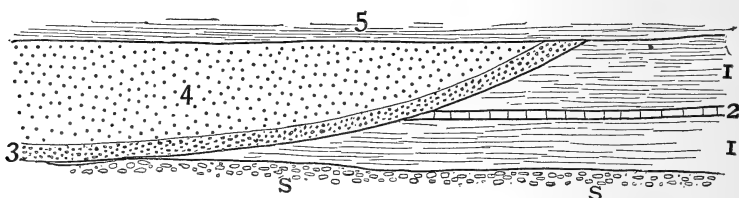
The thicknesses of these beds are variable, especially that of the lower ironstone, and its upper surface seems to be uneven. The upper bed of ironstone is very similar to the bed so well-developed at this horizon in most of the inland sections.

About halfway between Saltwick Nab and Whitby, a very interesting phenomenon may be seen. A small synclinal flexure here brings the junction of the Estuarine Series and the Lias down to high-water mark, and at the lowest point of the syncline there is

clear evidence of contemporaneous erosion. In the highest beds of the Lias a large hollow has been formed, and this hollow is filled with a mass of false-bedded sandstone, which passes laterally into shale. At the base of this sandstone is a layer of ferruginous conglomerate, with grains of glauconite; and this is continued for some distance to the east as a hard bed of ironstone, which is very well exposed on the beach, forming a sort of raised shelf at the foot of the cliff.

The appended figure gives a diagrammatic representation of this interesting section: unfortunately, the lower portion is often partly hidden by accumulations of shingle and seaweed.

Fig. 1.—*Contemporaneous erosion of the Lias, East Cliff, Whitby.*



5 = Shales of the Estuarine Series.

4 = False-bedded sandstone.

3 = Ferruginous conglomerate.

2 = Ironstone-band.

1 = Upper Lias (Alum-Shale).

S, S = Shingle of beach.

This is evidently a case in which a channel, cut in the Lias by a current, has been filled by material of Oolitic age.

Immediately west of this wash-out the Dogger is unusually thin, thus:—

Thickness in feet inches.	
Flaggy sandstone above.	
Ironstone .....	1 6
Pebble-Bed .....	0 3
Very ferruginous shale .....	2 0
Hard Alum-Shale below.	

The 2-foot bed of ferruginous shale is merely the uppermost layer of the Alum-Shale, stained by infiltration from above. The Pebble-Bed is here very well marked, and contains pebbles of the usual character, but often measuring as much as 3 inches in diameter.

On the eastern side of Whitby Harbour the Dogger is inaccessible for some distance, being about 40 feet above high-water mark under the East-Pier Ladder; but loose blocks abound on the beach, and the whole Dogger Series often falls down in one block. It consists of about  $2\frac{1}{2}$  feet of reddish-grey ferruginous sandstone above, with a concretionary base 1 foot thick, consisting of large calcareous nodules, and very numerous black pebbles up to 3 inches in diameter at the bottom, decreasing in size upwards. The upper bed of sandstone contains much carbonaceous matter, chiefly stems

of plants in a vertical position. No other fossils were found at this horizon west of Saltwick Nab.

### (3) Sandsend and Kettleness.

In the Sandsend alum-works the junction is very clearly shown. The Dogger is here represented by some 3 feet of impure ironstone, generally resting directly upon the Alum-Shale without any pebble-bed; but, in one or two places, a few pebbles are seen. About a quarter of a mile farther, at the eastern end of the long tunnel, the Dogger is completely absent, and sandstone of the usual Estuarine type rests directly upon the Alum-Shale.

From this point to Kettleness the junction runs close to the top of high cliffs, and is quite inaccessible; but, at one point near the middle of the long tunnel, sandstone may be plainly seen resting in a hollow in the Lias.

Immediately east of the shorter tunnel a very clear section is exposed; the succession is as follows:—

#### *Thickness in feet.*

Very false-bedded yellow sandstone.	
Pebble-Bed .....	1
Ironstone.....	1
Alum-Shale.	

The Pebble-Bed is here much thicker than usual, and almost merits the name of a basal conglomerate. The most noteworthy point is that the ironstone-band is below the Pebble-Bed, and must therefore belong to the Lias. Here, again, Estuarine Sandstone rests directly upon the Lias, with only a pebble-bed at the base, and true Dogger is absent.

All over this district the false bedding of the sandstone is very remarkable, and indicates the prevalence of shallow water and strong currents.

### (4) Boulby Cliff.

In the large alum-quarries of Boulby Cliff the Dogger is very well displayed, and shows some interesting features. At the western end of the easternmost excavation the following section was measured:—

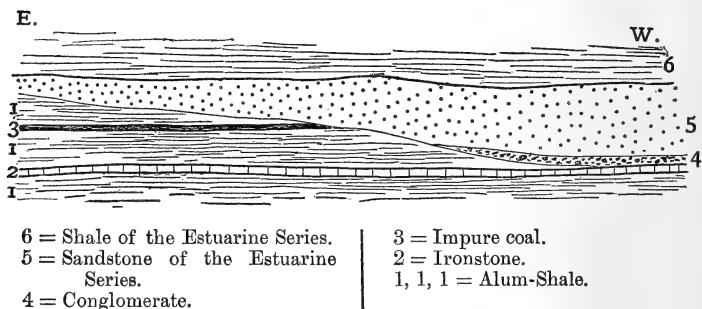
#### *Thickness in feet inches.*

Massive, very soft, pinkish-white sandstone.		
Oolitic ironstone .....	1	0
Conglomeratic rock, with white fragments .....	2	0
Concretionary ironstone .....	1	0
Soft black clay .....	0	3
Black carbonaceous shale .....	0	6
Nodular ironstone .....	1	0
Alum-Shale below.		

The rock which is described above as a 'conglomerate' is most peculiar. It is a ferruginous oolitic rock, with black and white fragments, and a few very badly-preserved fossils (apparently lamelli-branches, among which *Astarte* alone is distinguishable).

At the eastern end of the same excavation the succession is different. Above the lowest band of nodular ironstone come in 10 feet of shale with lines of small doggers; then 1 foot of black shale, almost a coal-seam, succeeded by another 5 feet of shale; and then a thin bed of sandstone, which is continuous with the thick sandstone of the western end of the quarry.

Fig. 2.—*Boulby alum-works, eastern quarry.*



It is evident that here, at the eastern end of the section, the sandstone rests upon an eroded surface of Lias; the Dogger seems to be represented only by the basal conglomerate at the western end, and is absent towards the east.

At another point in the Boulby-Cliff quarries, immediately above the ruins of the old buildings at the western end, the massive sandstone descends very low, and rises again sharply within a short distance; there is no fault, and the overlying beds a little way above remain horizontal. At the base of this mass of sandstone the section is as follows:—

	<i>Thickness in feet inches.</i>	
Very thick, massive, brown sandstone.		
Ironstone, with white fragments.....	1	0
Pebble-Bed .....	0	3
Shale, with ferruginous partings .....	3	0
Ironstone .....	0	4
Shale .....	0	3
Soft ironstone .....	2	0

The Pebble-Bed is here evidently the line of separation, and the beds below it belong to the Lias. The upper limit of the mass of sandstone is inaccessible and not clearly defined, but the depth of the hollow in which it lies cannot have been less than 50 feet.

In this neighbourhood the most striking feature is the very uneven line of demarcation between the Lias and the Oolites, giving clear evidence of contemporaneous erosion and unconformity.



## IV. INLAND SECTIONS.

## (1) Falling Foss and Littlebeck.

Along the east side of this valley are a few exposures of the Dogger, from which many fossils can be obtained.

At Falling Foss, by the side of the waterfall, the succession is:—

<i>Thickness in feet.</i>	
Estuarine Series above.	
Fine-grained ferruginous sandstone.....	8
Coarse red rock, with pebbles and white fragments; many fossils.....	4
Blue Liassic shale below.	

The 4-foot bed consists of a coarse, reddish-grey, conglomeratic rock, containing numerous angular white fragments. This is exactly like the rock seen at the Peak alum-works and many other localities. The fossils are not in good preservation, but the following can be identified:—

<i>Pentacrinus.</i>	<i>Pleuromya</i> sp.
<i>Ceromya bajociana.</i>	<i>Sowerbya.</i>
<i>Modiola plicata.</i>	<i>Cerithium muricatum.</i>
<i>Pecten arcuatus.</i>	<i>Pseudomelania procera.</i>
<i>Pecten barbatus.</i>	<i>Alaria arenosa.</i>
<i>Pecten demissus.</i>	
<i>Avicula Münsteri.</i>	<i>Belemnites.</i>
<i>Cardium striatulum.</i>	

In a small stream, half a mile north of Newton House, the following interesting section is exposed:—

<i>Thickness in feet.</i>	
An extremely-variable bed, in some parts a coarse pebbly grit, in others a yellow sandstone, or even an oolitic ironstone becoming flaggy at the top .....	12
Soft yellow sandstone, weathering into concentric ferruginous coats .....	2½
Pebble-Bed, with badly-preserved fossils .....	1
Soft yellow sandstone .....	1½
Blue Liassic shale, very rotten.	

The Pebble-Bed consists of unusually-large pebbles, measuring up to 1½ inches in diameter, of the ordinary character. The fossils, although very numerous, are badly preserved. The following are determinable:—

<i>Trigonia striata.</i>	<i>Pseudomelania procera.</i>
<i>Pecten demissus.</i>	<i>Turbo lavigatus.</i>
<i>Pinna</i> sp.	
<i>Pholadomya.</i>	<i>Belemnites.</i>

And a fragment of an ammonite, probably derived.

In the Littlebeck alum-works the lower part of the Dogger is very fossiliferous; it is, for the most part, the peculiar red conglom-

meratic rock before described, passing locally into a coarse yellowish sandstone. The fossils occur only as internal casts, and therefore determination is difficult :—

*Avicula inæquivalvis.*  
*Pholadomya Sæmanni.*  
*Pecten demissus.*  
*Trigonia striata.*  
*Goniomya angulifera.*

*Nerinea cingenda.*  
*Cerithium quadrivittatum.*  
*Turbo levigatus.*  
*Pleurotomaria* sp.  
*Alaria.*

The facies of this small fauna is quite indisputable evidence of its horizon, although the exact relations of the beds cannot be made out.

## (2) Eskdaleside.

At the alum-quarry on Eskdaleside, commonly known as Spence Works, is a very fine exposure of Upper Lias and Estuarine Beds. The junction is accessible at several points, and admirably clear; the succession is as follows :—

	<i>Thickness in feet inches.</i>	
Soft yellow Estuarine Sandstone.		
Hard, blue, calcareous shale .....	1	9
Blue shale, false-bedded .....	1	0
Impure coal .....	1	6
Soft, ferruginous, shaly sandstone, with lenticles of shale ...	7	0
Red, fine-grained rock, in large blocks with thick ferruginous coatings, in four beds .....	8	0
Pebble-Bed .....	0	3
Soft grey clay .....	0	6
Soft blue Alum-Shale.		

**Pebble-Bed.**—The lower pebbles are embedded in a soft grey clay, 4 to 6 inches thick, which passes gradually up into the overlying bed; but the bulk of them are enclosed in the ferruginous scaly coatings which surround the blocks of red rock. The pebbles become smaller upwards, and small ones are scattered through the red grit for a few inches upwards. The scaly coats surrounding the blocks of red grit are often 4 or 5 inches thick, and separate it into large cubical or rounded blocks, of very peculiar character.

These beds are almost unfossiliferous.

## (3) Glaisdale.

We now come to what is, perhaps, the most interesting and satisfactory of all the inland sections, and second in importance only to the section at Blea Wyke itself.

In the neighbourhood of Glaisdale the Dogger contains much more iron than usual, so much so that it was worked as an ore, for the supply of the long-defunct Glaisdale Ironworks. It was worked by drifts on the west side of the dale, and from the spoil-heaps below these drifts many fossils can be obtained.

The total thickness of the Dogger at Postgate Hill is about 12 feet, practically all ironstone, but it is too poor in quality for profitable working under present industrial conditions.

Fossils are very numerous, both in species and individuals; but the preservation is poor, nearly all occurring as internal casts only. I have been able to identify the following:—

*Acrosalenia* sp.

*Rhynchonella cynocephala*.  
*Rhynchonella subobsoleta*.  
*Rhynchonella subtetrahedra*.  
*Terebratula spheroidalis*.  
*Terebratula submaxillata*.  
*Terebratula trilineata*.

*Lima cardiiformis*.  
*Hinnites velatus*.  
*Gervillia Hartmanni*.  
*Gervillia lata*.  
*Gervillia tortuosa*.  
*Gresslya peregrina*.  
*Trigonia denticulata*.  
*Trigonia striata*.

*Astarte elegans*.  
*Modiola aspera*.  
*Ostrea flabelloides*.  
*Ostrea solitaria*.  
*Pinna cuneata*.  
*Ceromya bajociana*.  
*Cardium acutangulum*.  
*Cardium gibberulum*.  
*Cardium striatulum*.  
*Quenstedtia oblita*.

*Nerinea cingenda*.  
*Nerita costata*.  
*Turbo* (?)

*Serpula deplexa*.

The commonest forms are *Terebratula trilineata*, *T. submaxillata*, and *Hinnites velatus*.

The most noteworthy feature of this fauna is the abundance of brachiopods and lamellibranchs, and the rarity of gasteropods. The occurrence of *Terebratula trilineata* and *Nerinea cingenda* in the same bed is sufficient to show that we are here dealing with a condensed representative of a much thicker series in the coast-section, where the *Terebratula*-Bed and the *Nerinea*-Bed are separated by 26 feet of yellow sandstone. The general character of this assemblage of fossils likewise suggests that it represents only the upper part of the Blea Wyke section, that is, the Dogger proper and the Yellow Beds. It appears, therefore, that even in this, the most complete inland section, the *Serpula*- and *Lingula*-Beds are unrepresented, and there is no sign of any gradual passage upwards from the Lias.

My thanks are due to Miss M. Keighley, of Spring-Hill House, Whitby, for kindly allowing me to examine her large collection of fossils from this locality.

## V. THE NORTH-WESTERN DISTRICT.

Along the north-western escarpment of the Cleveland Hills, from the sea-coast to the neighbourhood of Battersby and Burton Head, a distance of some 20 miles, the Dogger can hardly be said to exist as an independent bed; but about the head of Bilsdale it again becomes conspicuous.

Just below the singular group of blocks of sandstone known as

the Wainstones, on Hasty Bank, there is an interesting exposure of the Dogger, which is here very different from its eastern development. The section is as follows:—

	<i>Thickness in feet inches.</i>	
Massive sandstone, very thick.		
Ferruginous, thinly-bedded, dark shale .....	20	0
Shale, with ferruginous nodules .....	5	0
Flaggy ironstone, with shaly partings .....	2	0
Irregular nodular ironstone .....	1	0
Blue shale .....	0	3
Ironstone-doggers, with scaly coats .....	2	0
Shale, with belemnites and pebbles .....	2	0
Liassic shale below.		

Here a thickness of about 25 feet, of rather variable shaly beds, comes in between the usual nodular ironstone with scaly coats and the massive sandstone above, whereas in most of the eastern sections the Dogger ironstone is immediately succeeded by sandstone.

It is evident, on the most casual inspection, that the distance between the line of old workings (indicating the Jet-Rock), and the escarpment of the Estuarine Sandstone varies greatly in this district, and in the small valley which runs down the west side of Hasty Bank into Bilsdale this is very clearly seen. In one place sandstone *in situ* may be seen within 30 or 40 feet of the Jet-Rock, and this sandstone must lie in an eroded channel in the shale of the *communis*-zone, which is usually at least 100 feet thick. This trough is evidently of considerable length, as it can be seen also in Raisdale, on the other side of Cold Moor, more than a mile to the south-west.

In connection with the Pebble-Bed with rolled belemnites, at the base of the Dogger at the Wainstones, Prof. P. F. Kendall<sup>1</sup> has published an interesting and important note. He has observed a very strong resemblance between the pebbles at the Wainstones and the Middle Liassic ironstone of Kildale, and from this he draws two conclusions:

‘(1) That, as there was an extensive denudation of the Lias during the deposition of the Dogger, it is not improbable that the Dogger ironstone may have derived much of its material from the denudation of the Middle Lias ironstone.’

According to my view, denudation of the Lias took place before the formation of the Dogger, during the period when the only beds deposited in this neighbourhood were those of Blea Wyke, and possibly some of the ironstone of Glaisdale.

Prof. Kendall continues:—

‘The other reflection is that, as the lowest horizon of the Lias to which the Dogger erosion-plane has cut in the Cleveland area is still above the Jet-Rock, there must exist elsewhere some old axis of disturbance, along which the Lias was folded and denuded before or during the Dogger time, actually down to the Lower Lias. As the Upper Lias is practically intact right down to the Humber, except for pre-Cretaceous erosion on the Market-Weighton anticline, I think that the source of the Lower and Middle Lias débris in the Dogger must be sought to the north of the Cleveland area, perhaps on some of the folds which can be shown to have been produced in pre-Permian times, and accentuated by subsequent movement.’

<sup>1</sup> ‘The Naturalist’ 1902, p. 216.

## VI. SUMMARY AND CONCLUSIONS.

A consideration of these sections yields several interesting results. A perfectly-complete transition from the Lias to the Lower Estuarine Series is seen only at Blea Wyke. Elsewhere the change from Alum-Shale to Dogger is abrupt: in a few localities only do we find some of the peculiar fossils of the Blea Wyke Beds, in the lower part of the Dogger. In all sections are to be seen some signs of unconformity, and in most cases this is clearly shown by the occurrence of a well-marked basal pebble-bed.

It is plain that, except at Blea Wyke, the Dogger rests upon an eroded surface of Upper Lias, usually on some part of the *Ammonites communis* Zone, but in different localities on somewhat different horizons. In many places the Lias has been worn, by current-action, into large hollows, and in these have been deposited lenticular masses of sandstone.

Besides the basal conglomerate, bands of similar rounded fragments and concretions often occur at various other horizons. Such phosphatic pebbles always indicate shallow-water conditions, and are generally associated with contemporaneous erosion, as in the case of the Cambridge Greensand.

Over the greater part of North-East Yorkshire there exists a considerable break in the stratigraphical succession between the top of the Lias and the base of the Oolites. The evidence shows that at this time peculiar physical conditions prevailed, notably shallow water and strong currents over a wide area. The explanation of this state of things is probably as follows:—After the deposition of the Lias there was a period of slow elevation, which caused the newly-formed strata to be uplifted within reach of wave- and current-action. But it appears that the northern half of the district was more elevated than the southern, and that, as first suggested by Mr. Hudleston<sup>1</sup> in 1873, the Peak Fault is partly of pre-Oolitic date. This fault formed a submarine cliff, and in the still water at its foot the Blea Wyke Beds were laid down. Eventually the upward movement ceased, the hollow below the fault-scarp was filled up, and the Dogger proper was laid down as a continuous bed over the whole area.

The occurrence of pebbles of Middle Liassic ironstone in the basement-conglomerate of the Wainstones is important, since it shows that in some direction, probably towards the north, the uplift must have been much greater. This confirms the idea that the lapse of time between the deposition of the Lias and that of the Dogger was greater than would appear at first sight, and that the apparent conformity is, in Yorkshire, to a large degree deceptive.

The movements that produced this period of uplift may be regarded as the forerunners of those which, at a later date, produced slight local unconformities in the Middle Jurassic strata of the Midland Counties. These small uplifts are connected by Prof. Kendall with repeated movements of the Charnian Ridge, and the same influence may have extended into the North of England.

<sup>1</sup> Proc. Geol. Assoc. vol. iii (1872-74) p. 304.

## DISCUSSION.

The CHAIRMAN (Mr. H. B. Woodward) remarked that the abstract of the Author's paper did not sufficiently indicate the new matter which he contributed; but he had undoubtedly raised many points for discussion, in connection with the evidences of local erosion and of derived fossils at the base of the Dogger.

Mr. FOX STRANGWAYS complimented the Author upon the very clear way in which he had put before the Society the relationship between the Lias and the base of the Oolites in so interesting a district. There were, however, a few points as to which further information was required. One was in reference to the so-called 'pebbles' of the Dogger. What were they? Some were undoubtedly worn fragments of other rocks, but they were not all so. Some were phosphatic, and there were concretions of various kinds. Many authors had alluded to this, but no one seemed to have given a satisfactory explanation. The Author stated that the Lias was denuded before the deposition of the Dogger, but if the pebbles were derived from the Middle Lias, the denudation must have been contemporaneous.

The Blea-Wyke Beds were stated to be unrepresented elsewhere, but there were certain beds at Castle Howard which Mr. Hudleston considered to be of that age. The base of the Dogger was taken at a higher horizon than by previous authors. There did not seem to be sufficient reason for this; and, as the line now proposed was in the midst of a thick mass of sandstone, it would be impossible to trace such a line across country.

Mr. HUDLESTON said that he was naturally much interested in a paper which offered a fresh description of the Blea-Wyke Beds, while showing their relation to the Dogger as ordinarily developed throughout North-East Yorkshire. He had always been much impressed with the immense difference between the development of the Dogger on the east and on the west side of the Peak Fault. It was to be regretted that the Author had been unsuccessful in his search for fossils in the Grey Sands which constitute the platform at Blea-Wyke Point. Dr. Wright was the first to indicate the importance of the Cephalopoda of this horizon, which he justly compared with his 'Cephalopoda-Bed' at Frocester and elsewhere in the Cotteswolds; while more recently Mr. Buckman had described numerous forms of the ammonite-genera *Oxynoticeras* (*Hudlestonia*), *Grammoceras*, etc., based upon specimens from this spot. Within the space of  $1\frac{1}{5}$  miles, reckoning from Blea-Wyke Point, the whole of this series, comprising some 150 feet of beds, is missing on the north-west side of the fault, and the Dogger is reduced to some 4 feet, with the usual pebble- or nodule-bed towards the base.

There could be no doubt that many of these bodies were remanié forms, mainly derived from the contemporaneous erosion of the Upper Lias; and they had in many cases been partly phosphatized, like the derived forms in the Cambridge Greensand. One of the chief lessons to be learnt from the geology of this region was

the enormous amount of denudation undergone by the Upper Lias in North-East Yorkshire, especially north-westward of the Peak Fault, previous to, and in part contemporaneous with, the deposition of the Oolites: an instance was given in one of the Author's diagrams. He had himself suggested many years ago that this fault was a line of weakness, which had moved more than once in the history of the district. It was well known that the movement of faults was often secular in character, and that disturbances of the earth's crust were apt to follow old lines. The different developments at the Peak called for some explanation, and if, during deposition, one side of the area was going up while the other side was going down, the existing state of things might have been the consequence.

He could not agree with the Author's description of the Blea-Wyke section, where so large an amount of the Dogger was assigned to the Yellow Sands. There was upwards of 30 feet of rock, consisting of an arenaceous and partly-oolitic ironstone of a peculiar chocolate-colour, some of the beds containing a large percentage of metallic iron. The lithology of the Yellow Sands was totally different from this, nor was there anything in the palæontology of the beds to suggest such an innovation in the reading of the section. Although dissenting in this respect, he thanked the Author for his graphic presentation of the subject.

Mr. R. S. HERRIES welcomed a new paper on these interesting beds, and thought that the Author's views were probably, on the whole, correct. It was obvious that the existence of some 170 feet of beds on one side of the fault, which did not occur on the other, was not a mere accident; and it was difficult to avoid drawing the inference that there had been a movement along the present fault-line, at a time more or less contemporaneous with the deposition of the *Striatulus*-Shales and the Blea-Wyke Beds, as originally suggested by Mr. Hudleston. There were two ways of accounting for the absence of the beds on the north side of the fault—non-deposition and erosion. He (the speaker) was inclined to adopt the latter theory, at any rate in part, as there seemed to be traces of the *Striatulus*-Beds in the junction-sections in places. He instanced especially the beds in the Lofthouse alum-works, and called attention to the occurrence of a *Lingula* in the Dogger at High Whitby and Saltwick, and to the existence of a bed of *Terebratula trilineata* (with numerous other Dogger fossils) between Sandsend and Kettleless. He thought that the problem could best be settled by a careful working-out of the fossils at all the different localities.

Prof. WATTS referred to the importance of this communication, in view of the possibility of a fault moving during the deposition of strata. He suggested that the Blea-Wyke Beds, being of the downthrow type, might be expected to occur elsewhere, and that their absence would prove to be the exceptional, rather than the normal, condition.

The AUTHOR thanked the Fellows for the kindly way in which they had received his paper. In reply to Mr. Fox Strangways, he observed that he had used the term pebbles, for the rounded bodies

found at Blea Wyke and at the base of the Dogger elsewhere, in the sense in which it was employed by the older writers, as a purely-descriptive term, and fully agreed that many of these 'pebbles' were concretionary. He had drawn the base of the Dogger at Blea Wyke below the *Nerinea*-Bed, so as to bring it into line with the thickness observed at other sections. He was quite aware that ammonites were fairly abundant at Blea Wyke, as stated by Mr. Hudleston, but were rare elsewhere. As Mr. Herries remarked, fossils were abundant at some of the other sections described, but their manner of preservation rendered identification difficult, except at Glaisdale, where the fauna was large and comparatively well-preserved.



23. *On the AGE and RELATIONS of the PHOSPHATIC CHALK of TAPLOW.*

By HAROLD J. OSBORNE WHITE, F.G.S., and LLEWELLYN TREACHER, F.G.S. (Read April 5th, 1905.)

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## I. INTRODUCTION.

IN the course of an investigation of the Upper Chalk in the western part of the London Basin, we had occasion, last autumn, to examine the pit at the South Lodge of Taplow Court, to which so much attention was attracted twelve years ago by Mr. A. Strahan's discovery of the richly-phosphatic character of some of the beds therein exposed.

It was originally intended to devote no more than a few paragraphs to this section, in a short account of the highest beds of the Chalk and their relations with the Lower Eocene sediments in the whole area, which we have in preparation; but the difficulties in the way of a satisfactory interpretation which presented themselves at the preliminary inspection referred to, and seemed, for a time, but to increase with succeeding visits, compelled us to undertake a minute examination of the beds, and the results of this work now appear to be of sufficient interest to merit the more detailed discussion obtainable in a separate paper.

In dealing with the phenomena of a single exposure of a rock having so wide a lateral range as the Chalk, some loss of the sense of continuity and of proportion is usually inevitable; but a separate treatment of the Taplow-Court section appears to be justified, no less by the remoteness of the beds from any visible Chalk of a similar age, than by their exceptional lithological character.

References to the Phosphatic Chalk of Taplow are numerous and widely scattered, but in the present communication it will suffice to give a brief résumé of only the more important works on the subject.

The earliest notice occurs in Mr. Whitaker's memoir on the 'Geology of London,'<sup>1</sup> where it is described as a 'greyish gritty chalk in blocky masses, resembling Totternhoe Stone, without flints,' 20 feet in thickness, underlain by 40 feet of white chalk with very few flints, and succeeded by 10 feet of the same. *Belemnitella quadrata* and *Ostrea acutirostris* are stated to be common in the

<sup>1</sup> Mem. Geol. Surv. vol. i (1889) pp. 77 & 78.

middle greyish bed, the occurrence of the former and the scarcity of flints suggesting 'a correlation of this Chalk with the well-known Margate Chalk or the zone of *Marsupites*.' A diagrammatic section is given (*op. cit.* p. 78), showing the *Micraster cor-angulum* Chalk of the country between Marlow and Maidenhead passing, south-eastwards, beneath the Taplow Beds.

In his paper 'On a Phosphatic Chalk with *Belemnitella quadrata* at Taplow,'<sup>1</sup> which forms the most important investigation of the subject hitherto published, Mr. Strahan briefly describes the Taplow-Court Lodge Pit, draws attention to the phosphatic nature of the 'greyish' chalk above mentioned, and details the results of a chemical, mineralogical, and microscopical examination of the richer layers of phosphate. The latter are compared with similar beds found at several horizons in the Chalk of Northern France and Belgium; and their relation to the ordinary Chalk of the district and some evidence of their strictly-local occurrence are also considered.

Mr. Strahan points out that there are two well-marked phosphatic bands, separated by a considerable thickness of white chalk, the higher and thicker band including *Echinocorys vulgaris*, Breyn., and *Cidaris sceptrifera*, DeFrance (*sic*), in addition to the two forms already named. A short list of foraminifera (prepared by Prof. T. Rupert Jones) is included in the paper; but, with the exception of *Inoceramus*, no other macroscopic fossil is recorded from any part of the section.

The Taplow Chalk is indirectly referred to the zone of *Marsupites*, that is, 'to the same horizon approximately' as the phosphatic deposits of Doullens, Hardivillers, etc., in the North of France, which 'may . . . be attributed to' that zone.

A short article on 'Phosphatic Chalk,' by the same author, published in 'Natural Science' for June 1892,<sup>2</sup> relates chiefly to the same deposit, with regard to which it is observed:—

'It is, doubtless, of a lenticular form, and probably of no great extent. The other pits and sections in the neighbourhood . . . seem, in the few cases where they expose the right zone in the Chalk, to lie beyond the limits of the lenticle. What these limits are, and in what directions the lenticle extends, can only be determined by borings or by tunnelling from the known outcrop. . . '

It is pointed out that, although the deposit is at a horizon which here lies

'close beneath the Tertiary beds, . . . in other districts, and even in the immediate neighbourhood of Taplow, these strata rest upon other parts of the Upper Chalk, either higher or lower than that in which the phosphatic beds are situated,' and that 'therefore we require [in searching for the phosphate-bearing zone in this country] a surer guide than that afforded by the Tertiary boundary.'

Such a guide Mr. Strahan appears to find in the Chalk-Rock, but he does not show how it is to be employed, and he suggests that

'some further assistance may be rendered by the existence of zones in the Upper Chalk, characterized by certain fossils.'

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlvii (1891) pp. 356-66.

<sup>2</sup> Vol. i, pp. 284-87.

The Taplow-Court section was visited by the Geologists' Association in July of that year, but the Report<sup>1</sup> of the excursion, so far as it relates to the Phosphatic Beds, consists almost entirely of extracts from the last-mentioned essay. It is evident, however, from the character of the material collected by the present writers, quite independently, on that occasion, that the attention of the party was mainly directed to the higher phosphatic band. A sample of Chalk from this horizon was sent by one of us to Mr. F. Chapman, who, later in the same year, published a lengthy list of foraminifera obtained therefrom.<sup>2</sup>

Between the years 1892 and 1904 no fresh information relative to this section seems to have been published,<sup>3</sup> though a good deal of desultory fossil-collecting was carried on by occasional visitors. In the meantime, great progress was made in zoning the Upper Chalk of the southern parts of this country by Drs. Rowe & Blackmore, and Messrs. Brydone, Griffith, Jukes-Browne, W. Hill, Sherborn, and others; and two results of this work having an important bearing on the age of the Taplow phosphates were (1) the establishment of a definite line of demarcation between the zones of *Actinocamax* (*Belemnitella*) *quadratus* and *Marsupites*, and (2) the recognition that the true *Actinocamax quadratus* (Defrance) rarely or never occurs below its own zone. At this stage, therefore, the student with no other evidence before him than that afforded by the literature of the subject, might reasonably have inferred that the Taplow Chalk, with its abundant *Actinocamax quadratus*, belonged to a distinctly higher horizon than the Margate Chalk. That such was the view taken by French geologists may be gathered from the fact that Prof. A. de Lapparent, in the third edition of his 'Traité de Géologie' (1900), places the 'Craie phosphatée de Taplow' in the Campanian stage, between the 'Craie de Norwich' and the (Santonian) 'Craie de Margate.'<sup>4</sup>

In the early part of 1904, however, there appeared the third volume of Mr. Jukes-Browne's memoir on 'The Cretaceous Rocks of Britain,' containing some remarks on the Taplow Chalk which, while they cast a grave doubt on the correctness of this inference, are well calculated to reawaken an interest in that rock. The passages in this work which deal directly with the deposit contain no reference to the occurrence of *Actinocamax quadratus*,<sup>5</sup> the place occupied by that species in previous accounts being taken by *A. granulatus* (Blainville)—a form which ranges down into the *Micraster cor-anguinum*-Zone. No reason is given for this important

<sup>1</sup> By the late J. H. Blake, Proc. Geol. Assoc. vol. xii (1892) pp. 406-408.

<sup>2</sup> 'Microzoa from the Phosphatic Chalk of Taplow' Quart. Journ. Geol. Soc. vol. xlviii (1892) pp. 514-18.

<sup>3</sup> The Phosphatic Beds are discussed by Dr. W. Fraser Hume, Proc. Geol. Assoc. vol. xiii (1894) pp. 238-39, and compared with those of Southerham by Messrs. Strahan & Chapman, Quart. Journ. Geol. Soc. vol. lii (1896) pp. 463-72. See also the second footnote on p. 486 of this paper.

<sup>4</sup> Tableau, pp. 1406-1407.

<sup>5</sup> The mention of this species on p. 376 is probably a clerical error.

change, and we are left to infer that the earlier determination of the Taplow belemnoid was incorrect.

With regard to the Chalk itself, it is observed :—

‘Fossils are very scarce in the lower part of the section, but Mr. Rhodes [the fossil-collector to the Geological Survey] obtained *Galerites albogalerus* near the bottom. As no plates of *Marsupites* were found, it is doubtful whether any part of the section is referable to the zone of *Marsupites*, and it certainly cannot belong to the zone of *Actinocamax quadratus*.’<sup>1</sup>

Mr. Jukes-Browne thinks that it is ‘in all probability equivalent to the [*M. cor-anguinum*] Chalk of Cliffe and Gravesend,’ in Kent (*op. cit.* p. 207).

The foregoing outline of former work on the Taplow Phosphatic Chalk will serve to demonstrate the desirability of a thorough examination of the Lodge section. We have there a group of beds, less than 70 feet thick, referred, directly or by implication, to three distinct zones of the Upper Chalk (the thinnest of which commonly exceeds 100 feet in this country<sup>2</sup>), mainly on the evidence of six fossil species, not one of which—so far as can be gathered from the published descriptions—is really diagnostic.<sup>3</sup> The conclusions derivable from data so scanty and imperfect are of little value; and, in the absence of more definite evidence, the safest course appears to be that taken by Mr. Jukes-Browne, who refers the beds, provisionally, to the zone of *Micraaster cor-anguinum*, which is known to contain all the fossils so far recorded from them, and to include the higher part of the Chalk of much of the surrounding country.

## II. DESCRIPTION OF THE BEDS.

The position and surroundings of the long-abandoned quarry showing the Phosphatic Chalk above mentioned may be indicated in a few words. It is situated on the left bank of the Thames, at the southern end of the steep, wooded river-scarp, or bluff, which forms the western side of the spur supporting the village of Taplow, in Buckinghamshire. The higher part of this spur, the summit of which lies between 120 and 150 feet above the river, consists of an outlier of the Reading Beds, capped with gravel, extensive spreads of which, and of finer alluvial drift, also envelop the adjoining lower ground on the west, south, and south-east. To the north-west, on the farther side of the Thames Valley, extend the Chalk uplands of the Chilterns, bearing other Eocene outliers; while to the south, east, and north, at distances of  $1\frac{1}{2}$  to  $2\frac{1}{2}$  miles, the main

<sup>1</sup> ‘The Upper Chalk of England’ Mem. Geol. Surv. 1904, p. 220.

<sup>2</sup> See vertical sections, *ibid.* fig. 79, p. 446.

<sup>3</sup> It was not until our work was well advanced that we obtained, by the kindness of Mr. H. A. Allen, the following list of fossils from this pit in the Geological-Survey collection, at Jermyn Street:—*Echinocorys scutatus*, Leske, var. *pyramidatus*; *Ostrea acutirostris*, Nilss. (? *O. Wegmanniana*, d’Orb.); *Inoceramus*; *Actinocamax granulatus* (Blainv.).

mass of the Tertiary strata of the London Basin comes on with an extremely-irregular, drift-observed boundary.

The dominant south-eastward inclination of the solid rocks is reflected in the prevailing surface-slope of the higher ground of the neighbourhood, but their secondary tectonic features have little or no definite topographical expression; and, as will be shown in the sequel, the internal structure of this piece of country is somewhat less simple than outward appearances would suggest at first sight.

Before dealing with the section and its faunal sequence in detail, it will be advisable to quote the stratigraphical succession made out by Mr. Strahan (Quart. Journ. Geol. Soc. vol. xlvii, 1891, p. 356), which we found useful as a guide during the earlier stages of our examination:—

	Feet inches.	
(11) 'Soft white chalk, top not seen .....	12	0
passing down into		
(10) Brown chalk with <i>Ostrea acutirostris</i> , Nilss., <i>Belemnites quadrata</i> , Defrance (both abundant), <i>Echinocorys vulgaris</i> , Breyn., and <i>Cidaris sceptrifera</i> , Defrance [sic] about	8	0
(9) White chalk, traversed by numerous tubes and cavities filled with brown chalk; a hard and blocky top, forming a marked floor to the brown chalk above .....	3	0
(8) White chalk, mostly inaccessible, and not examined in detail .....	14	0
(7) White chalk with scattered brown grains .....	2	6
passing down into		
(6) Brown chalk .....	about 4	0
(5) Hard crystalline chalk, with nodular structure and greenish markings (like Chalk-Rock) .....	about 1	0
(4) White chalk, piped with brown chalk, as above .....	1	10
(3) A sandy brown layer .....	0	0½
(2) White chalk, piped with brown chalk .....	2	6
(1) White chalk to the bottom of the pit, the first flints occurring 12 feet below the lower band of brown chalk .....	15	0+

[The numbers in parentheses have been attached by us to facilitate reference.]

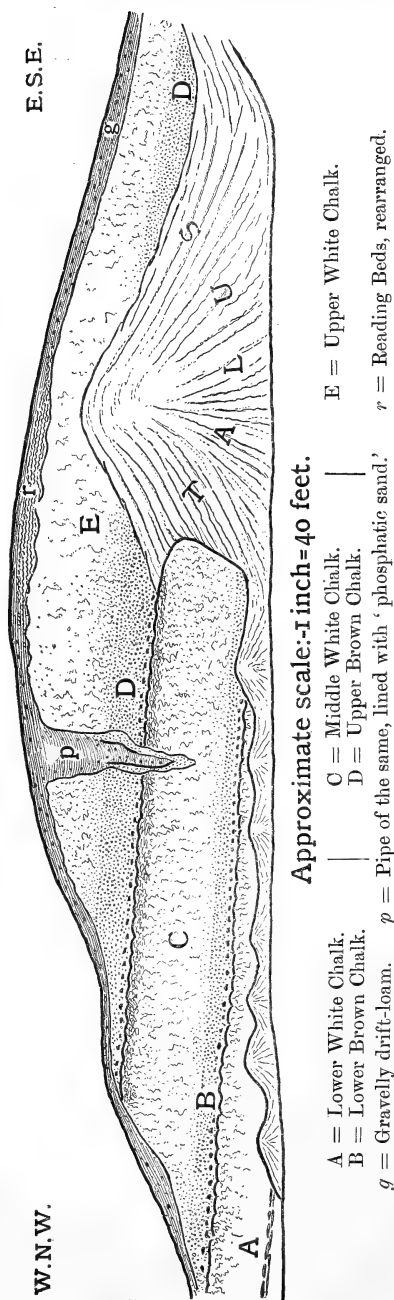
Our reading of the section differs in some respects from the above. The divergence is, no doubt, mainly attributable to the broader character of the present investigation, Mr. Strahan having, apparently, devoted his attention almost entirely to the smaller lithological features of the rich phosphatic bands. The more important points on which we differ from him will be noted as they arise.

We find it convenient to divide the section into five parts, as follows:—

	Feet.
E. Upper White Chalk (11) ..	visible 16
D. Upper Brown Chalk, or rich phosphatic band (10) ...	about 8
C. Middle White Chalk (9, 8, 7) .....	about 16
B. Lower Brown Chalk, or rich phosphatic band (6) ...	about 4
A. Lower White Chalk (5, 4, 3, 2, 1) .....	visible 17

[The numbers in parentheses indicate the equivalent beds in Mr. Strahan's succession.]

Fig. 1.—Section at the South Lodge, Taplow Court.



Approximate scale: 1 inch = 40 feet.

A = Lower White Chalk.  
 B = Lower Brown Chalk.  
 g = Gravelly drift-loam.

C = Middle White Chalk.  
 D = Upper Brown Chalk.

E = Upper White Chalk.

p = Pipe of the same, lined with 'phosphatic sand.'  
 r = Reading Beds, rearranged.

In the accompanying diagram of the Lodge section (fig. 1), which is approximately to scale, the salients and re-entrants of the face of the quarry have been smoothed away, and the details much simplified and conventionalized. The thick growth of trees, bushes, and creepers, and much of the talus, are also omitted. In the section itself the dip of the beds is, approximately south-eastward, at angles ranging from  $4^{\circ}$  or  $5^{\circ}$  on the left, or western half, of the exposure, to about  $8^{\circ}$  on the right (where, however, an accurate measurement is difficult to obtain).

The several divisions will be dealt with in alphabetical, or ascending order.

#### Division (A).

This is a rather soft, white, blocky chalk, with greyish venules, becoming finer, more compact, and rather firmer in its upper parts, and passing gradually into a hard rock-bed, from 6 to 18 inches thick, at the top. Near the bottom, at the western end of the pit, is a thin layer of tabular flint, succeeded, a few inches above, by one of elongate, solid, nodular flints, with very thin to decidedly - thick white rinds. These were the only flints noticed *in situ* in the whole section.

The first signs of phosphatic material were observed a few inches below the tabular flint-seam. At that horizon small, scattered fish-remains, coprolites, and rare phosphatized foraminifera become noticeable; and with them are associated a few dull, yellowish-brown, subangular phosphatic concretions, from a sixteenth to a quarter of an inch in diameter, with minute crevices or perforations, and chalky inclusions. These materials disappear and recur throughout the higher beds of this division, but their distribution is too irregular to allow of their being referred to definite bands.

At about 6 feet above the flints (or 8 feet from the top of this chalk) polished brown granules, consisting of the small phosphatized organic matter just mentioned, but with a much larger proportion of foraminifera, and identical with those forming upwards of 60 per cent. of much of the overlying Brown Chalk, appear in bunches in an iron-stained paste filling ill-defined tubes or 'borings'; and within the next 2 or 3 feet similar granule-filled tubes come in abundantly, their number increasing, but by no means steadily, as the summit of this division is approached. These borings are, broadly speaking, of two types: (1) the sharply-defined, sub-cylindrical, and branching, and (2) the vague, irregular, and digitate; but many intermediate forms exist. Despite the existence of such passage-forms, we are not satisfied that the contents of the vaguer sort are due, in every case, to intromission from above. Here, and also in the other white chalks of the section, the localization of the brown granules is often more suggestive of some process of segregation, or, at least, of development along certain paths. The more regular borings (from  $\frac{1}{4}$  to 1 inch in diameter) of the Taplow Chalk do not exhibit the curious ridging at the junction of stem and branch to be seen in their analogues in the Chalk-Rock of Lewes and elsewhere. They are best developed in the higher beds of this division, and there they often contain the phosphatized casts of sponge-stems and the glazed nodules which characterize the lower portions of the overlying Brown Chalk.

In the higher beds, also, spherical and vermiform concretions of dark red iron-peroxide (decomposed pyrite) are of rather frequent occurrence.

We have not observed a definite bed exhibiting the character and occupying the position of Mr. Strahan's half-inch 'sandy brown layer' (numbered 3); but there are many impersistent seams of such sandy material, up to 3 or 4 inches in thickness, following curved and rectangular joints, or fissures, in the higher beds. These seams consist very largely of phosphatic granules, with little or no chalky investment, and the presence of quartz-grains, brown clay, carbonaceous matter, and rootlets of trees, shows them to be merely the result of the mechanical and chemical action of atmospheric water percolating through the overlying rich phosphatic bands.

Mr. Strahan's description of the rocky layer (5) capping the lower white beds, as 'a hard crystalline chalk, with nodular structure and greenish markings (like Chalk-Rock),' is sufficient for most purposes, but needs some amplification here. For, in this bed, there

are to be observed the strongly-undulate upper surface, with its coarse brown enamel or glazing, encrusting *Serpula* and *Plicatula*, and agglutinated foraminiferal, coprolitic, and other remains; the innumerable minute and larger perforations (many of the former being empty); the iron-staining; the minute rhombs of clear calcite; the clustering dendrites of manganese-dioxide,—in short all, or nearly all those features which characterize the hardened layer usually forming the floor of the thicker masses of Phosphatic Chalk in the North of France.<sup>1</sup>

The substance forming the glaze above described appears to be nearly-pure calcium-phosphate. It varies from the merest film to a mammillated crust from a sixteenth to an eighth of an inch thick, enveloping and penetrating the small fossils which adhere to the upper surface of the rock-bed, and descending into fissures in the latter. The relations of this mineral to the above-described borings are remarkably variable and interesting. Commonly sealing-up the mouths of these tubes, it not infrequently forms a sort of selvage to their soft contents for a depth of from 1 to 6 inches below their upper ends; but in many cases it has permeated and hardened the brown chalk within them, while in other instances it has left both the walls and the contents of the borings unaltered. It is clear that the glazing post-dates the filling of some of the borings, at least, and, to judge from appearances, also the induration of the rock-bed.

The following is a list of the fossils obtained by us from this division (A).

[NOTE.—In this and succeeding lists the letters r. c. = rather common; c. = common; v. c. = very common. Species not so qualified may be regarded as rare.]

Pisces. (c.)

*Corax falcatus*, Ag.

*Inoceramus Cuvieri*, Sow. (v. c.)

*Lima (Plagiostoma) cretacea* (?) Woods.

*Ostrea* spp.

*Pecten (Neithea) quinquecostatus*, Sow.

*Teredo amphibæna*, Sow.

*Crania parisiensis*, Defr.

*Cidaris clavigera*, Koenig.

*Cidaris sceptrifera*, Mant.

*Terebratulina striata*, Wahl.

*Membranipora* sp.

*Echinocorys scutatus*, Leske.

*Galerites albogalerus*, Leske.

Asteroidea. (r. c.)

*Micraster cor-anguinum*, Klein. (r. c.)

*Micraster cor-anguinum*, var. *latior*, Rowe.

*Bourgueticrinus ellipticus*, Miller.

*Porosphæra globularis*, Phil.

*Porosphæra patelliformis*, Hinde.

*Coscinopora infundibuliformis*, Goldf.

*Plocoscyphia convoluta*, T. Smith.

*Ventriculites alcyonoides*, Mant.

*Ventriculites decurrens*, T. Smith. (c.)

*Ventriculites infundibuliformis* (?)

S. P. Woodw. (r. c.)

*Ventriculites radiatus*, Mant.

The majority of these were collected in the upper half of the division (that is, within 8 feet of the top), from the white chalk between the borings. The lower half yielded little but remains of *Inoceramus*.

*Bourgueticrinus* is represented by very small columnal and brachial ossicles, and *Echinocorys scutatus* by fragments of medium thickness.

<sup>1</sup> See J. Gosselet, Ann. Soc. Géol. du Nord, vol. xxiv (1896) pls. ii & iii.



The *Micrasters* and siliceous sponges are from the rock-bed, and from immediately below it. Some of the former and all of the latter are in the form of phosphatized casts. In a few instances, the sponge-stems have been found in rather closely-fitting, conical pits in the upper surface of the rock.

*Porosphaera globularis* is of small size, measuring only 6 to 12 millimetres in diameter.

### Division (B).

The lower limit of this, the Lower Brown Chalk, is everywhere clearly defined by the above-described rock-bed; its upper limit is very ill-marked. We adopt Mr. Strahan's measurement of 4 feet (see p. 465) for the thickness of this division, which seems as good as any that can be made out.

The lower part, for a distance of 1 to 6 inches above the rock-bed, is usually a brown, or greyish-brown, ferruginous sand, consisting mainly of phosphatized foraminifera and prisms of *Inoceramus*, small coprolites, chips of echinid-tests and oyster-shells, with other more or less minute organic débris, and containing many fish-teeth and a variable quantity of coarser material in which may be distinguished:—

1. Rounded nodules and casts of *Micraster*, and of stems of ventriculate sponges, consisting of hard greenish- or yellowish-white chalk, encrusted with *Serpula* and other small organisms of adnascent habit, and enveloped in a dark-brown glaze ..... to 4 inches in maximum diameter.

These are evidently rolled and phosphatized pieces of the rock-bed.

2. Angular and rounded pieces of the same chalk, speckled with manganese, within, and either unglazed or but partly glazed, without ..... to 2 inches.
3. Angular and subangular concretions, hard, brown, microgranular or homogeneous, and often partly glazed ..... to half an inch.
4. Irregular, slightly-calcareous concretions of brick-red, or brown iron-oxide ..... to a third of an inch.

Nos. 2 & 3 are also clearly derived from the same source as No. 1, the latter representing portions of the agglutinated contents of the borings. As these, and No. 4, have only a local development, and seem to be confined to the sandy layer, it is probable that they result from the decomposition of the rock-bed at a comparatively recent date. The bed referred to shows, in many places, a tendency to fracture, or scale, along surfaces between  $\frac{1}{4}$  and 1 inch below the glaze, the detached pieces resembling the partly-glazed material of Nos. 2 & 3.

5. Compact or finely-granular, dull-yellow, brown, or greenish concretions of angular or subangular—less often of rounded—form, with perforations, and of a somewhat softer and more earthy character than those of No. 3, from which, however, they are not always to be distinguished ..... to a third of an inch.

These are distributed throughout the brown beds above. Like the concretions noted in (A), which they closely resemble, they have probably been formed *in situ*.

The sandy layer, which in many places contains quartz and flint-chips, and other adventitious matter introduced through fissures from above, passes up into a yellowish- to greyish-brown, firm, phosphatic chalk, resembling friable sandstone, with widely-spaced subrectangular joints, and a fine and exceedingly-complicated banding or graining, suggestive of an original lamination all but destroyed by the combined action of boring organisms and of differential movements within the body of the rock. The glazed nodules observed in the sandy seam are recognizable in these firmer beds, but become decidedly scarcer towards the top. Impersistent seams of yellowish chalk-pebbles are locally prominent in the lower 2 feet.

Towards the top of the band the rock assumes a greyer tinge, the fine layers, or stripes, of brown chalk becoming obviously interspersed with others of lighter, yellowish or white, colour.

As the salient microscopic features of this, and of the higher, rich phosphatic band have been described by Mr. Strahan, it is unnecessary to enter into further details.

On weathered surfaces the rock is covered by a greyish sandy coating, through which the more durable materials, such as the nodules and fossils, project.

The Lower Brown Chalk has yielded remains of the following forms:—

Pisces. (v. c.)	<i>Scalpellum maximum</i> , Sow.
<i>Corax falcatus</i> , Ag. (c.)	<i>Serpula fluctuata</i> , S. P. Woodw. (c.)
<i>Corax pristodontus</i> (?) Ag.	<i>Serpula plana</i> , Sow.
<i>Lamna appendiculata</i> , Ag. (v. c.)	<i>Serpula</i> spp.
<i>Odontaspis macrorhiza</i> , Cope.	<i>Cidaris hirudo</i> , Sorig.
<i>Scapanorhynchus</i> sp. ?	<i>Cidaris sceptrifera</i> , Mant. (c.)
<i>Actinocamax verus</i> , Miller. (c.)	<i>Cidaris serrifera</i> , Forbes.
<i>Inoceramus Cuvieri</i> , Sow.	<i>Pseudodiadema (Halicodiadema) fragile</i> , Wilts.
<i>Lima Hoperi</i> , Mant.	<i>Echinocorys scutatus</i> (fragments).
<i>Ostrea hippopodium</i> , Nilss. (r. c.)	<i>Galerites albogalerus</i> (fragments).
<i>Ostrea semiplana</i> , Mant. (c.)	<i>Micraster cor-anguinum</i> , Klein. (r. c.)
<i>Ostrea vesicularis</i> , Lam. (v. c.)	<i>Bourgueticrinus ellipticus</i> , Miller.
<i>Ostrea Wegmanniana</i> . (c.)	<i>Marsupites testudinarius</i> , Schloth.
<i>Ostrea</i> spp. (?). (c.)	<i>Uintacrinus</i> sp. (c.)
<i>Pecten cretosus</i> , DeFr.	<i>Asterioidea</i> . (r. c.)
<i>Plicatula sigillina</i> , S. P. Woodw. (c.)	<i>Pentagonaster megaloplax</i> , Sladen.
<i>Spondylus latus</i> , Sow. (c.)	<i>Porosphera globularis</i> , Phil.
<i>Teredo amphibæna</i> , Sow. (r. c.)	<i>Coscinopora infundibuliformis</i> , Goldf.
<i>Crania</i> sp.	<i>Ventriculites decurrens</i> , T. Smith. (c.)
<i>Kingena lima</i> , DeFr.	<i>Ventriculites infundibuliformis</i> (?)
<i>Rhynchonella reedensis</i> , Eth.	S. P. Woodw.
<i>Terebratulina striata</i> , Wahl.	<i>Nodosaria Zippei</i> , Reuss.
<i>Scalpellum fossula</i> , Darw.	

*Uintacrinus* is represented by detached plates and brachial ossicles, mostly obtained from the sandy layer at the bottom of the band. The highest plate found was situated 2 feet 3 inches above the

rock-bed, which was also about the position of the single, slightly-ornamented scute representing *Marsupites*.

The examples of *Actinocamax verus* and *Ostrea semiplana* were all obtained within a foot of the bottom, and occurred throughout the length of the exposure of this division. The guards of *A. verus* are of slender form, with the rather acutely-pyramidal anterior end figured by Schlüter in 'Palæontographica,' vol. xxiv (1876-77) pl. lii, fig. 9.

*Micraster cor-anguinum*, *Ventriculites*, and *Coscinopora* occur as phosphatized casts, and are, most probably, derived from the underlying bed, to the upper surface of which, and to the glazed nodules, the more or less completely-phosphatized examples of *Spondylus*, *Plicatula*, *Serpula*, and *Crania* were attached.

The foraminifer *Nodosaria Zippei* is here of sufficient size and frequency to be included in a list of macroscopic fossils. It has not been recognized in the form of a phosphatic cast. The remaining forms were scattered through the division, but more sparingly in the upper than in the lower half.

*Porosphaera globularis* is rare and very small (diameter = 3 mm.).

### Division (C).

The lower rich phosphatic band assumes a lighter cast towards its upper limit, owing to the decrease in the proportion of the brown grains (and also, in some measure, to a loss of the yellowish tinge of their fine calcareous paste), and, somewhere between 4 and 5 feet above its base, passes into a soft white chalk, with brownish-grey seams and patches. Wherever this middle white division of the section is examined, grains of phosphate are clearly visible. It is a true Phosphatic Chalk, and its separation from the richer, brown band below, although convenient for descriptive purposes, seems a somewhat arbitrary proceeding from the lithological standpoint.

Besides the disseminated brown grains, large borings, both regular and irregular, filled with the same, occur at all levels; and though but little of the middle part of the division is accessible, we doubt the possibility of obtaining a cubic foot of the chalk free from such perforations at any horizon. Towards the upper limit they are so closely set, as almost to replace the white chalk between them, and to give the rock the aspect of a breccia.<sup>1</sup>

Pale-brown earthy concretions, with soft chalky inclusions are locally very prominent, and attain a larger size ( $1\frac{1}{4}$  inches in diameter) than in other parts of the section.

The top of these beds is marked by a hard nodular layer, from a few inches to 1 foot thick, possessing the undulate upper surface, and, less prominently, the brown glazing, manganese-dendrites, and many of the other lithological features of the bed that occupies a similar position in the Lower White Chalk; but it is generally distinguishable from the latter in hand-specimens by its paler,

<sup>1</sup> A similar pseudo-breccia in the phosphatic beds near Fresnoy-le-Grand (Aisne), is figured by Prof. J. Gosselet, Ann. Soc. Géol. du Nord, vol. xxi (1893-94) p. 154.

yellowish hue, its more brecciate aspect, and by a paucity of adherent organisms.

The jointing in this division is, on the whole, frequent and rectangular; but in the lower half there is, in addition, a sub-horizontal system which divides the chalk into biconvex lenses, from 2 to 15 feet in diameter and from a few inches to 4 feet in depth. At the surface of these lenses there is frequently a hardened pellicle exhibiting a shallow grooving and a high polish, probably attributable to slickensiding. Irregular seams of brown phosphatic sand, with quartz-grains and earthy matter, occur in the joint-fissures of the lower beds, near the middle of the pit. We regard all such sandy layers, whether conformable to the general stratification or otherwise, as post-Cretaceous decomposition-products.

Fossils are very scarce, and we can record only the following remains:—

Pisces.

*Corax falcatus*, Ag.

*Inoceramus* sp.

*Ostrea vesicularis*, Lam. (r. c.)

*Serpula fluctuata* (?) S. P. Woodw.

*Echinocorys scutatus*, var. (cf.) *pyramidatus*, Portl.

*Micraster cor-anguinum* (?) Klein.

*Metopaster Parkinsoni*, Forbes.

*Pentagonaster megaloplar*, Sladen.

*Echinocorys* is represented by rather stout fragments, but part of a test referable to the var. *pyramidatus*, and clearly derived from this division, was found on the talus.

### Division (D).

The Upper Brown Band, which of all the divisions of the Lodge section has received the most attention from former observers, resembles the Lower in its brownish to yellowish-grey colour, in its friability, in its massive jointing, and in the conglomeratic character of its lower parts. There are, however, many minor points of distinction, which become apparent on a closer inspection. Among these may be mentioned the greater abundance of the small brown or yellowish-green concretions (to five-eighths of an inch) and of remains of *Ostrea* and belemnoids, and the lighter colour of the larger débris (subangular and pebbly pieces of firm white and yellow chalk) of the beds below.

Boring organisms have been rampant at this horizon, their *Terebella*-like productions often weathering-out as cylindrical plugs, which are sometimes seen to terminate upwards at smooth brown laminæ—possibly bedding-planes.

Under the microscope, samples of this chalk are generally distinguishable from those of the Lower Brown Band (B) by the smaller size and larger variety of the foraminifera, and by the greater prominence of the Textularidæ and of rod-like objects.

There is the same lack of definition in the upper limit of this division as was noted in the case of the Lower Brown Chalk, the rich phosphate grading into the white beds above.

In protected spots the fossils stand out in high relief on the weathered sandy surface, and commonly exhibit a bluish-grey

staining at their edges. Where more exposed, the rock rapidly exfoliates, and the fossils are much less apparent on the convex faces of the blocks.

These beds have yielded:—

Pisces. (v. c.)	<i>Entalophora Pergensi</i> , Greg.
<i>Corax falcatus</i> , Ag. (c.)	<i>Scalpellum fossula</i> , Darw.
<i>Corax pristodontus</i> (?) Ag.	<i>Serpula plana</i> , S. P. Woodw.
<i>Lamna appendiculata</i> , Ag. (c.)	<i>Echinocorys scutatus</i> , Leske.
<i>Oxyrhina</i> sp.	<i>Echinocorys scutatus</i> , var. (cf.) <i>pyramidalis</i> , Portl. (c.)
<i>Actinocamax granulatus</i> (Blainv.) (v. c.)	<i>Cidaris sceptrifera</i> , Mant. (r. c.)
<i>Inoceramus Cuvieri</i> , Sow. (c.)	<i>Galerites</i> (?)
<i>Ostrea hippopodium</i> , Nilss. (c.)	<i>Micraster cor-anguinum</i> , Klein. (c.)
<i>Ostrea vesicularis</i> , Lam. (v. c.)	<i>Marsupites testudinarius</i> , Schloth. (r. c.)
<i>Ostrea Wegmanniana</i> , d'Orb. (v. c.)	Asteroidæ.
<i>Ostrea</i> spp.	<i>Porosphæra globularis</i> , Phil.
<i>Pecten Nilsoni</i> , Goldf.	Plantæ (?).
<i>Plicatula sigillina</i> , S. P. Woodw. (c.)	
<i>Spondylus latus</i> , Sow.	

The plates of *Marsupites* (nearly all incomplete) are of the patterns usually found in the midst of the *Marsupites*-Band<sup>1</sup>; the bulk of them exhibit a well-marked divergent ridging, and the remainder a faint tuberculation, or blunt radial plication. A plate of the last-named type was found about 1 foot below the top of the Brown Chalk, and the others within a distance of 2 feet above the bottom. The distribution of *Marsupites* in the Upper Brown Chalk, therefore, much resembles that of *Urtacrinus* in the Lower.

The abundance of guards of *Actinocamax granulatus* at all levels is most remarkable, and, we believe, quite unexampled in the Chalk of this country. One of us has observed as many as seven, in a space estimated at rather less than 60 cubic inches. The majority are distinctly granulated, the stouter forms often very markedly so, and their size is, on the whole, rather below the average of the examples found in the *Micraster cor-anguinum* and *Marsupites*-Zones of other English sections.

Owing to differential movements within the beds (which have frequently fractured and 'faulted' the guards, and crushed their weaker proximal ends) and to the difficulty of extraction from a rock which is at once tough and brittle, not more than 10 per cent. of our examples are whole. In these, the depth of the alveolar cavity ranges from a ninth to a fifth of the length of the guard, the average ratio being about 1:7.<sup>2</sup>

Taking into consideration all those examples, complete or otherwise, in which the anterior end is well preserved, the alveoli have, generally, a more markedly-quadrate section, and a greater depth, than those of the guards of *Actinocamax granulatus* from the

<sup>1</sup> For a definition of this term, see A. W. Rowe, 'Zones of the White Chalk, &c. Pt. I' Proc. Geol. Assoc. vol. xvi (1900) p. 296.

<sup>2</sup> The importance of stating such measurements, in all cases where the species is doubtful, will be gathered from a perusal of M. A. de Grossouvre's 'Observations sur les Bélemnites, &c.' Bull. Soc. Géol. France, ser. 3, vol. xxvii (1899) p. 129.

*Marsupites*-Band of the Margate district in Dr. Rowe's extensive collection; and in one stout, imperfect specimen the depth of the cavity will even bear comparison with that exhibited by some individuals of *Actinocamax quadratus*, from the Phosphatic Chalk of Beauval (Somme), Orville (Pas-de-Calais), and other French localities, in the same collection.

Dr. Rowe and Mr. G. C. Crick agree, however, in referring a selection of the alveolated specimens (including the extreme types) obtained by us from this part of the Taplow section to *Actinocamax granulatus* (Blainville).

The examples of *Echinocorys scutatus*, var. *pyramidatus*<sup>1</sup>—of which we have eight in well-preserved condition, as many others capable of identification, and the Museum of Practical Geology, Jermyn Street, has, at least, two more—closely approach the shape-variations commonly found in the higher part of the *Marsupites*-Band in this country; but all fall far short of the average in point of size. The length and height of the largest complete test in our collection are 51·5 millimetres and 33 mm., and of the smallest 30·5 mm. and 21 mm. respectively. The latter, as Dr. Rowe has pointed out to us, closely resembles the dwarfed pyramidal form characteristic of the lowest beds of the *Actinocamax-quadratus* Zone. Among the incomplete examples there are still smaller forms. The second variety is a depressed ovoid form, with a marked prolongation of the posterior end. It is represented by a single complete example, 55·5 mm. in length and 31 mm. in height, and by another fragmentary specimen, apparently of rather smaller dimensions. The nearest affinity is probably the var. *gibbus*, for we find a rather similar form merging into that variety in the *Micraster cor-testudinarium* and *Holaster-planus* Zones of the Thames Valley. A specimen somewhat resembling it is in the National Collection at South Kensington,<sup>2</sup> and Dr. Rowe has seen similar forms (but without the posterior development) in the base of the *Actinocamax-quadratus* Zone, and also in beds of *Micraster cor-anguinum* age. But, although it may be possible closely to match the individuals of *Echinocorys scutatus* occurring in the higher beds of the Taplow Phosphate from the normal Chalk, the whole facies of the species there is an exceedingly-rare, if not a unique one, for this country.

Remains of *Echinocorys* are plentiful throughout the Upper Brown Chalk, and particularly so in the lower 3 feet, where, however, we have obtained only stout fragments.

*Ostrea vesicularis*, by far the commonest macroscopic fossil at this horizon, occurs singly, and in thin, closely-superposed seams. This, or *O. Wegmanniana*, is probably the form alluded to as '*O. acutirostris*' in previous accounts of the section.

The largest example of *Porosphæra globularis* is but 5 millimetres in diameter.

<sup>1</sup> See remarks on this variety in Dr. Rowe's 'Zones of the White Chalk of the English Coast: Pt. IV—Yorkshire' Proc. Geol. Assoc. vol. xviii (1904) pp. 255-56.

<sup>2</sup> No. 34693, from the 'Chalk' of 'Kent.'

A group of fin-bones of a fish, about 6 inches in length; fish-teeth with fragments of bone attached; and small carbon-lined cavities of angular section (= wood?) are among the objects collected from this division.

It should here be noted that the tests for phosphorus, in the larger fossils of the brown chalks of Taplow, applied by Mr. Strahan were not sufficiently exhaustive to justify the important inference that the phosphate of lime in those beds 'is confined to the foraminifera and to the small organic remains embedded with them.'<sup>1</sup> Apart from the concretions present at most levels, and the obviously-phosphatized sponges, *Micrasters*, *Spondyli*, *Plicatulae*, *Serpulae*, etc. occurring in the Lower Brown Band (which that author seems to have overlooked), a rather large proportion of the macroscopic fossils in both brown bands gives evidence of phosphatic impregnation. Some of the larger remains, such as those of *Ostrea*, *Inoceramus*, and *Actinocamax* (outer layers of guard), which, by reason of their tenuity, or lamellar or prismatic structure, are more readily penetrable, often give the characteristic reaction with ammonium-molybdate after repeated and destructive cleansing with strong acids, and continue to do so until entirely destroyed. Others, of more homogeneous character—as, for instance, plates of *Cidaris*, *Echinocorys*, and *Marsupites*—usually cease to react at an early stage in the process, showing the impregnation to have extended, in their case, but little below the surface; and, while it is true that there are many instances in which the samples do not respond to this delicate test, after the preliminary treatment for the removal of the visible adherent granules of the matrix, it is equally true that no well-represented class of organic material collected by us is wholly exempt from this impregnation.

The finest washings of the white or yellowish chalky paste of the brown chalks are rarely or never free from phosphorus.

### Division (E).

The Upper White Chalk is much obscured, and rather difficult of access. It is, as a whole, fine, white, and rather closely jointed. Soft in its lower parts, it becomes firm and lumpy higher up, and in the topmost 3 or 4 feet is very hard, and often of a semi-crystalline, horny, or porcellanous aspect, the detached blocks weathering into a nodular rubble at the base of the overlying drift. In these hard beds there is a noticeable recrudescence of dendritic manganese-dioxide. Save in this respect, and in that of their hardness, however, they do not resemble the rocky layers at the top of the preceding White Chalks (A & C).

Granules of brown phosphate of the usual types, and anastomosing tubules (or borings) containing the same material, are very numerous in the lower 4 feet, gradually decreasing upwards. The borings become very ill-defined as the hard beds are approached, and are

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 361.

barely perceptible within them. Occasional small coprolites, fish-teeth, phosphatized foraminifera, and the ubiquitous brown phosphatic concretions (up to three-quarters of an inch in diameter) occur up to the top of the division.

None of the 'scattered flint-nodes' mentioned in connection with this part of the section in Mr. Whitaker's 'Geology of London' (Mem. Geol. Surv. vol. i, 1889, p. 77) were seen by us.

The foregoing description of this division does not agree with the more general one given by Mr. Strahan, who refers to the rock as a 'soft' chalk<sup>1</sup> and as an 'ordinary non-phosphatic chalk.'<sup>2</sup> The latter expression is an unfortunate one, as it tends to strengthen the impression conveyed (perhaps unintentionally) by the context of the essay in which it occurs, that the Phosphatic Chalk of Taplow is a lenticular inclusion in the flinty (*Micraster cor-anguinum*) beds seen in the neighbouring pits.

The fossils found in the Upper White Chalk are:—

Pisces. (c.)	<i>Plicatula sigillina</i> , S. P. Woodw. (c.)
<i>Lamna appendiculata</i> , Ag. (c.)	<i>Terebratulina striata</i> , Wahl.
<i>Oxyrhina</i> sp.	<i>Serpula annulata</i> , Reuss.
<i>Actinocamax granulatus</i> (Blainv.) (c.)	<i>Serpula plana</i> , Sow. (c.)
<i>Scalaria decorata</i> (?) Roemer.	<i>Cardiaster</i> (?)
<i>Inoceramus Cuvieri</i> , Sow. (r. c.)	<i>Echinocorys scutatus</i> , Leske. (c.)
<i>Ostrea hippopodium</i> , Nilss. (r. c.)	<i>Galerites albogalerus</i> , Leske.
<i>Ostrea lateralis</i> , var. <i>striata</i> , Nilss. (r. c.)	<i>Oreaster bulbiferus</i> , Forbes.
<i>Ostrea vesicularis</i> , Lam. (c.)	<i>Pentagonaster megaloplax</i> , Sladen.
<i>Ostrea Wegmanniana</i> , d'Orb. (r. c.)	<i>Parasmilia</i> sp.
<i>Pecten cretosus</i> , DeFr.	<i>Porosphæra globularis</i> , Phil.
	<i>Ventriculites</i> sp.

Nearly all of the above are from the lower two-thirds of the division.

*Actinocamax granulatus*, though less frequently met with than in the rich phosphatic band below, is still a common fossil, and in any other section would be counted abundant. Not any of the guards found are complete. The granulation is, perhaps, rather more noticeable than in the majority of those obtained in the brown beds below, and the alveolus seems of moderate depth—about a sixth of the length of the guard, in the very few cases where a fairly-trustworthy measurement can be obtained. The species becomes very scarce towards the top of the section, and has not been seen in the hard beds.

The remains of *Echinocorys scutatus* are too incomplete to afford a sure indication of the shape of the test. The least damaged-specimens obtained are of small size, with a thin test, which, in one instance, possesses a curvature suggestive of a depressed ovate, or subgibbous, variety.

The small echinid-fragments referred to as *Cardiaster* (?) in the above list are certainly not those of *C. (Offaster) pillula*, Lam.

A seam of *Ostrea lateralis*, var. *striata*, was found about 8 feet above the very ill-marked base of this Chalk.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 356.

<sup>2</sup> 'Natural Science' vol. i (1892) p. 286.



The discovery of a gasteropod referable to the genus *Scalaria*, at this horizon of the English Upper Chalk, is believed to be unique. The fossil is represented by a portion of an internal cast, with small pieces of the shell adhering to it. Mr. Jukes-Browne, who has been so good as to examine the specimen for us, believes it to be a relic of *Scalaria decorata*, Römer (1841)=*Fusus costatostriatus*, Münster, in Goldf. 'Petref. Germ.' vol. iii, p. 23, & pl. clxxi, fig. 18 (1843)=*Scalaria fasciata*, Etheridge, 'Geol. of Cambridge,' Mem. Geol. Surv. (Pal. Appendix) 1881, p. 140 & pl. i, fig. 1.

Here, as in the lower divisions, *Porosphæra globularis* is quite small.

Above the Chalk, at the highest part of the section, there is a degraded relic of the mottled clays and greenish 'bottom-bed' of the Reading Series (*r*, fig. 1, p. 466); and to the east and west of this a wash of sand and gravelly loam (*g*) follows the slopes of the spur in which the pit is excavated.

The rudely-conical pipe of sandy clay and gravel (*p*), near the middle of the section, possesses, in its lower part, a thick selvage of brown phosphatic sand, and forms, we believe, the only-known English analogue of the valuable poches de sable phosphaté of Belgium and Northern France.

### III. CORRELATION OF THE BEDS.

It will be gathered from the foregoing description that the greater part of the beds in this section are referable to the zone of *Marsupites testudinarius*.

The uneven upper surface of the rock-bed which caps Division (A) may, with much probability, be regarded as the base of that zone. Immediately above this surface we have the conglomeratic, nodule-bearing, brown chalk with remains of *Uintacrinus*, *Marsupites*, and *Actinocamax verus*; below it, an unbroken sequence of white beds which, since they contain *Galerites albogalerus*, and high-zonal forms of *Micraster*,<sup>1</sup> and have so far yielded no fossil distinctive of the *Marsupites*-Zone, may be referred to the upper part of the zone of *Micraster cor-anguinum*.

The *Micraster cor-anguinum*-Beds.—Though the fossils in the Lower White Chalk (A) do not enable us to determine its precise position in the *M. cor-anguinum*-Zone, and the signs of erosion at its junction with the *Uintacrinus*-bearing beds above discount, in a measure, the value of the evidence from superposition, there can be but little doubt that it belongs to the highest part of that zone. For, if the fossils have little or no general value as subzonal guides, they serve at least to distinguish this White Chalk from the *cor-anguinum*-beds exposed in other sections in this district, which in no instance show the same assemblage of forms,

<sup>1</sup> A. W. Rowe, 'An Analysis of the Genus *Micraster*, &c.' Quart. Journ. Geol. Soc. vol. lv (1899) pp. 494 *et seqq.*

and which there are independent reasons (drawn from an examination of a much wider area) for assigning to horizons well below the upper limit of the zone at its full development.

The lithological distinction between the lowest division of this section and other *cor-anguinum*-beds occurring at a similar, a greater, or a less distance below the base of the Tertiaries in the neighbouring exposures, is much more pronounced. The fine texture of the chalk, the total absence of flints, the presence of small phosphatic concretions, and the unusual prominence of fish-remains and coprolites, in the upper 14 feet of this division (excluding the contents of the borings), are characters which serve at once to separate it from those beds, and to ally it to the succeeding, richly-phosphatic, *Marsupites*-strata.

The lithological relations of the Lower White Chalk to the overlying beds seem to us to warrant its inclusion in the phosphatic series; while these relations, together with its palæontological characters, render the former existence of any considerable thickness of higher *cor-anguinum*-beds between it and the Lower Brown Chalk with *Uintacrinus* improbable.

The *Marsupites*-Beds.—Turning to the *Marsupites*-Beds, it is evident that in the Lower Brown Chalk (B) we have the representative of the *Uintacrinus*-Band, or of some portion of it. Here, as in the type-section of that band, the eponymous crinoid is associated with *Actinocamax verus* and *Kingena lima*; but many of the characteristic and common forms of the Thanet cliffs and other exposures find no place in the list given above. Some of these apparently-missing fossils, such as the large dome-shaped *Echinocorys scutatus* and the bryozoa, may be present in a comminuted condition. Others, less fragile, as, for instance, the large *Porosphaera globularis*, the nipple-calyxed *Bourgueticrinus*, and *Terebratulina Roweii*, if not wanting, must be exceedingly scarce. We do not, however, pretend to have exhausted the possibilities of this division. Owing to the colour and adherent nature of the brown chalks, few of their smaller fossils are visible, much less recognizable, on the face of the pit or in detached blocks, and the bulk of those in our collection were obtained by the tedious processes of sifting and washing.

It need scarcely be pointed out that the occurrence of *Marsupites* so near the base of its zone is most unusual in this country.

The restriction of *Actinocamax verus* to the base of the Lower Brown Chalk establishes another parallel between the Phosphatic Chalks of Taplow and Picardy, for MM. A. de Grossouvre,<sup>1</sup> J. Gosselet,<sup>2</sup> and H. Lasne<sup>3</sup> observe the same thing in many workings near Doullens and elsewhere.

<sup>1</sup> Bull. Soc. Géol. France, ser. 3, vol. xxii (1894) p. lviii; & *ibid.* vol. xxviii (1899) p. 129.

<sup>2</sup> Ann. Soc. Géol. du Nord, vol. xxx (1901) p. 210; & *ibid.* vol. xxxi (1902) p. 60.

<sup>3</sup> *Ibid.* vol. xxxi (1902) pp. 57-59; and Bull. Soc. Géol. France, ser. 3, vol. xx (1892) pp. 223-24.

Prof. Gosselet believes that the *Actinocamax verus* in the lowest rich phosphate-beds (Craie grise inférieure) of the French sections has, in every instance, been derived from the local equivalent of the (A) beds of the Taplow-Court pit. This, however, is questioned by M. Lasne; and the fact that M. Rabelle<sup>1</sup> has found this fossil associated with *A. quadratus* in the higher bands of phosphate at Ribemont, on the Oise, shows that its range in the French deposits of this class is not quite so limited as Prof. Gosselet seems to imply. The examples of *A. verus* found at Taplow are, as already noted, of *Marsupites*-Zone form, and there is nothing in their appearance which particularly suggests a remanié origin. The species is very rare in the *Micraster cor-anguinum*- and *Marsupites*-Zones in the western part of the London Basin, only one doubtful specimen (from the former) having been as yet recorded.<sup>2</sup>

It is of interest to note that *Ostrea semiplana*, which also appears to be confined to the lower part of the Lower Brown Chalk here, is found in a like position at Hardivillers (Oise).<sup>3</sup>

The 16 feet of less-phosphatic White Chalk which succeeds the *Uintacrinus*-bearing brown band is singularly devoid of fossils possessing a primary, or even a secondary, zonal value,—at least in a recognizable form. The occurrence of *Marsupites*-remains above and below it may, perhaps, be considered to favour its inclusion in the *Marsupites*-Band. On the other hand, the solitary plate of that crinoid found below this division may well be one of those sporadic and 'premature' occurrences which are not unknown in the midst of the *Uintacrinus*-Band of other localities; and, as this white chalk passes insensibly into the brown beds below, and is sharply separated from those above, it is safer to refer it to the latter subdivision of the *Marsupites*-Zone. So far as we have seen, and have learned from other observers, this relatively-barren group of beds has no analogue in the coast-sections of the zone. In the western part of the London-Basin area, however, belts of practically-unfossiliferous chalk are a not uncommon feature of the *Uintacrinus*-Band, and it is possible that the (C) division of this exposure may be a local development of one of these.

The abrupt change from the zoologically-poor and uninteresting Middle White Chalk to the very fossiliferous Upper Brown Chalk, with its remains of *Marsupites*, *Micraster*, and *Echinocorys*, its unfailing supply of *Actinocamax-granulatus* guards, and its multitude of oysters, appears to mark the incoming of the *Marsupites*-Band proper. In the latter division (D), plates of *Marsupites* are nowhere abundant, and can rarely be found at a greater distance than 1 foot above the nodular rock-bed at the bottom. At that horizon, *Echinocorys scutatus* has been seen by us only in the form of small fragments, and the well-preserved examples collected from 2 to 7 feet above—which may be regarded as succeeding

<sup>1</sup> Ann. Soc. Géol. du Nord, vol. xxi (1893-94) p. 344.

<sup>2</sup> A. J. Jukes-Browne, 'Cretaceous Rocks of Britain: vol. iii—The Upper Chalk of England' Mem. Geol. Surv. 1904, p. 221.

<sup>3</sup> A. de Grossouvre, Bull. Soc. Géol. France, ser. 3, vol. xxii (1894) p. lviii.

rather than as associating with *Marsupites*—have already the blunted pyramidal and sub-gibbous forms typical of that higher portion of the zone, as defined by Dr. Rowe,<sup>1</sup> in which the name-fossil is normally scarce, or wanting. The occurrence of these depressed types of *Echinocorys*, the short vertical range of *Marsupites*, and the presence of *Ostrea lateralis* var. *striata* in the overlying White Chalk (E), show that the base of the *Actinocamax quadratus* Zone is not far distant, and even suggest that a small thickness of that zone is represented in the highest beds of the section.<sup>2</sup> Unfortunately, these beds are not only much obscured, but are also of such a hardness as to be almost unworkable for fossils, and their examination has thus far produced negative results.

The Upper White Chalk, although possessing some distinctive features, is yet so closely connected with the underlying division that it must, in the absence of definite evidence to the contrary, be assigned to the *Marsupites*-Band.

In view of the occurrence of indurated layers at the top of each of the preceding white chalks, the upward increase in its hardness suggests the proximity of a third rich phosphatic belt; but the coincident decrease in the proportion of brown granules in the borings does not encourage that idea.

The broad stratigraphical and zonal features of the section may, then, be tabulated as follows:—

E. Upper White Chalk.	}	<i>Marsupites</i> -Band.	} Zone of <i>Marsupites</i> . 44 feet exposed.
D. Upper Brown Chalk.	}	24 feet exposed.	
	[Erosion.]		
C. Middle White Chalk.	}	<i>Urtacrinus</i> -Band.	
B. Lower Brown Chalk.	}	20 feet.	
	[Erosion.]		
A. Lower White Chalk.		Higher part of the zone of <i>Micraster cor-angustum</i> .	17 feet exposed.

On comparing the distribution of the fossils in the Phosphatic *Marsupites*-Chalk of Taplow with that in the normal Chalk of the same zone in other, inland or coastal, exposures in the South of England, one is impressed by the exceedingly-small thickness of the beds yielding the characteristic erinoids. In view of the evidences of intra-formational erosion which are to be seen in the derived material within, and the uneven floors below, them, it seems not unlikely that each of these beds may represent only the highest part of a mass of sediment of similar palæontological characters, the rest of which was swept away soon after its deposition. There is, however, nothing to prove that the above-mentioned erosion accomplished anything more than the disintegration and removal of an irregular layer of the underlying White Chalk a foot or so in depth;

<sup>1</sup> 'The Zones of the White Chalk of the English Coast: Pt. I' Proc. Geol. Assoc. vol. xvi (1900) p. 338.

<sup>2</sup> Dr. Rowe has hitherto regarded *Ostrea lateralis* var. *striata* as characteristic of the zone of *Actinocamax quadratus*, op. cit. pp. 345, 365.

and, having regard to the mineralogical condition of the *Marsupites*- and *Uintacrinus*-bearing brown chalks, and to the concentration of fish-remains, belemnoids, oysters, and other fossils within them, it seems rather more probable that their small thickness is chiefly due to an initial defect of sediment. The currents which scoured and pitted the rock-beds may very well have hindered or prevented the deposition of the finer calcareous matter; and the closely-packed débris of the larger fossils (e.g., *Inoceramus*, *Echinocorys*, and *Micraster*) in the lower parts of the brown bands is in harmony with this idea. The presence of fine chalky paste in every part of the Brown Chalks (excepting, of course, the sandy decomposition-seams) at the present day does not constitute a grave objection, for even where the coarser material was washed clean, the chalk-mud of the succeeding whiter beds would inevitably have penetrated into their interstices—the mixing process being hastened by the boring organisms whose work is here so much in evidence.

The reduction in the total thickness of the zone of *Marsupites* at Taplow Court below that which was normal in this part of the country, arising from the small development of those characteristic stages that figure so prominently elsewhere, may have been considerable, but cannot now be even approximately gauged, as the erosion which preceded the deposition of the earliest Eocene sediments has left no accessible Chalk of that age within a distance of nearly 20 miles.<sup>1</sup>

Assuming the base of the zone of *Actinocamax quadratus* to have come in 10 feet above the highest beds of the Lodge section—and the evidence from the form of *Echinocorys* and the presence of *Ostrea lateralis* var. *striata* in the upper beds does not, we think, warrant a higher estimate—the total measurement of the *Marsupites*-Zone at this spot may be placed at about 55 feet. In East Kent, and in the Hampshire Basin generally, the published measurements and more trustworthy estimates of the thickness of this zone are much greater: usually exceeding, and rarely or never falling far below, 100 feet.

It would, however, be unsafe to assume that the shrinkage at Taplow which this discrepancy implies was due entirely to local causes, for, as we hope to show in a future communication, the zone did not attain so great a development over the western part of the London Basin as in the adjoining areas to the south and east.

When taken in connection with the exceptionally large number of individuals by which some other species are represented, the comparative scarcity of *Uintacrinus*, *Marsupites*, and *Porosphaera* and the absence, or great rarity, of many of their associates, which abound in the lower and middle divisions of the *Marsupites*-Zone in other districts, will admit of but one interpretation, namely, that the local conditions of existence were unsuited to these forms of life. It is evident that we have not here to deal with a merely-

<sup>1</sup> We deem it highly probable that *Marsupites*-Beds occur at a much less distance beneath the Tertiary formations to the south.

impoverished fauna, such as is too often the case in the rocks of the same age farther westward. The palæontological facies of the *Marsupites*-Beds of this section is scarcely less peculiar than the lithological; and if, in the latter case, the peculiarity does not wholly consist in a mineralogical accession to the normal Chalk of the zone (but in a group of correlative phenomena, of which the presence of an unusually-large proportion of calcium-phosphate is the most obvious and important), neither, in the former case, does it reside entirely in a zoological depletion. Mr. Strahan,<sup>1</sup> in this country, and the late Prof. Renard & M. Cornet,<sup>2</sup> in Belgium, have called attention to the prominence of fish-remains in all known phosphatic chalks. A further distinguishing feature of the Santonian and Campanian deposits of this class in North-Western Europe appears to be the abundance of individuals of belemnites and oysters; while, so far as we can gather from the literature of the subject, a dearth of many other forms common in the normal chalks is no less a characteristic of the French phosphates referable to those stages than of the single English example.

The fauna of the *Marsupites*-Beds of Taplow is, then, in a measure, a special one, adapted to the special, but little-known conditions under which phosphatic chalks were accumulated at widely distant points on the sea-floor, in late Cretaceous times.

The broader lithological features of the Taplow-Court section so closely resemble those of the phosphate-workings in the North of France, that the descriptions of the latter given by MM. Lasne, Gosselet, de Mercey, and other authors are, in many cases, applicable to the former, down to the smallest detail.

Attention has already been drawn to the similar distribution of certain fossils in the phosphatic chalks of Buckinghamshire and Picardy. How far this parallelism extends we are unable to judge, for despite the formidable dimensions which the literature of the French deposits has assumed during the last fifteen years, but little information is forthcoming on the subject of their fauna. It would seem that the higher phosphatic chalks of Northern France are generally less fossiliferous than ours, but the frequent allusions to oysters, belemnites, and sharks' teeth,<sup>3</sup> and the occasional references to plates of *Marsupites*,<sup>4</sup> suggest that a careful search would, in some instances, reveal a succession essentially similar to that at Taplow. The majority of the French deposits must, however, belong to a distinctly higher horizon, for in them *Actinocamax granulatus* seems a comparatively scarce form,<sup>5</sup> while *A. quadratus* is usually present, and *Belemnitella mucronata* not infrequently so.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 366.

<sup>2</sup> 'Recherches micrographiques sur la Nature & l'Origine des Roches phosphatées' Bull. Acad. Roy. Belg. ser. 3, vol. xxi (1891) pp. 126 *et seqq.*

<sup>3</sup> See M. Leriche, 'Révision de la Faune ichthyologique des Terrains crétacés du Nord de la France' Ann. Soc. Géol. du Nord, vol. xxxi (1902) pp. 87-154.

<sup>4</sup> For example, J. Gosselet, Ann. Soc. Géol. du Nord, vol. xxi (1893-94) p. 349.

<sup>5</sup> *Id. ibid.* vol. xxix (1900) p. 79.

#### IV. SOME FACTS BEARING ON THE MODE OF FORMATION OF THE PHOSPHATIC CHALK.

The nature of the conditions under which the Senonian Phosphatic Chalks of North-Western Europe were accumulated is a subject that has been dealt with at length by Continental geologists, and it is one which we, who are but imperfectly acquainted with the English examples of Taplow and Lewes alone, shall not presume to discuss. Some small service may, however, be rendered by calling attention to a few, relevant features of the Taplow section, which have not been recorded hitherto.

Among these features we note the concretionary phosphate, present in one form or another at almost all horizons.

In his review of the Cretaceous Phosphates, Dr. Teall<sup>1</sup> implies that Taplow is not one of those localities where this mineral group occurs 'in the form of detached nodules, or as nodular and more or less conglomeratic deposits.' Contrasted with the vastly-greater bulk of the granular, pseudomorphic variety, the amount of concretionary phosphate here is undoubtedly small, but by itself it would form a striking feature of any chalk in which it occurred; and the nodular and conglomeratic character of the lower parts of the brown chalks is so evident in this pit, that we must suppose Dr. Teall to have been familiar only with small hand-samples of the more homogeneous upper portions of those beds.

Here, as in the larger French deposits of the Pas-de-Calais, Somme, Aisne, and Oise, the direct precipitation of calcium-phosphate as a glaze upon the rock-beds seems, in each case, to have preceded the deposition of the main mass of the overlying brown chalk,<sup>2</sup> for the enamelled débris and sponge-casts of the rock-bed are scattered through the latter, together with slightly-altered pieces of white chalk. On the other hand, the formation of the glaze clearly post-dates that of the brown chalk filling those borings in the rock-bed the orifices of which it has sealed up, and the contents of which it has agglutinated; and, as the same glossy substance has been observed by us on the larger fossils (as, for example, *Ostrea*, *Inoceramus*, *Cidaritis*) near the base of (B), it would seem that its precipitation accompanied, or alternated with, the deposition of the lowest layers of brown chalk, in that case.

There is no reason to doubt that the dull, earthy-looking concretions, with inclusions of material identical with the surrounding rock, which are common to the white and brown chalks, were formed *in situ*, and represent phosphatized portions of their softer matrix. They are of all sizes, from  $1\frac{1}{4}$  inches in diameter downwards, and may be seen in many stages of development, ranging from brownish or yellowish stains to indurated lumps grating harshly under the knife.

<sup>1</sup> 'The Natural History of Phosphatic Deposits' Proc. Geol. Assoc. vol. xvi (1900) p. 382.

<sup>2</sup> L. Cayeux, 'Contribution à l'Étude micrographique des Terrains sédimentaires' Mém. Soc. Géol. du Nord, vol. iv, 2 (1897) p. 431.

The detection of the concretionary variety of phosphate here may not involve the rejection of the hypothesis<sup>1</sup> that the phosphatization of the foraminifera and other small organic remains, which form a large proportion of the brown granules of the Taplow Chalk, was performed elsewhere, but it greatly reduces its probability. With the striking evidence of the formation of calcium-phosphate on the spot before one, there seems little need for the supposition that those objects were imported, in their present condition, from some more or less distant and unknown source. Moreover, the principal argument in favour of that hypothesis, namely, the limitation of the phosphate to the foraminifera, and to the other micro-organisms associated with them, is shown, by more extended observation, to be not entirely in accordance with the facts: some of the larger fossils at certain horizons, and an appreciable, if small, proportion of the body of the Chalk at almost all horizons, having clearly undergone the same kind of alteration as the smaller organic débris of the brown granules.

Upholders of the derivation-hypothesis may, perhaps, find a new weapon in the marked difference presented by the phosphatized and the calcareous foraminifera of the White Chalks (C) and (E) into which the brown bands graduate upwards. Those which are partly or completely infilled or pseudomorphosed by phosphate are in better preservation, include a larger selection of species, and contain, in abundance, certain families (notably the Textulariidae and Globigerinidae) which are rare in the calcareous examples. It is very doubtful, however, whether this distinction existed at the time when the beds in question were laid down: whether, in fact, it may not be attributable to the relative indestructibility of the phosphatized forms, which, as M. Cayeux has shown,<sup>2</sup> survive those common but obscure structural changes in the Chalk that suffice to obliterate all but the stoutest of the unaltered individuals. In the white beds referred to we note that the calcareous foraminifera are mainly such resistant forms of Rotalidae as occur in most microscopic preparations of the Upper Chalk.

The richness of the Taplow deposits in individuals and in species of foraminifera is well known, but the possibility that its superiority in these respects over most ordinary Chalks of about the same age may not be altogether an inherent quality, seems to have escaped recognition. If, as M. Cayeux insists (*loc. cit.*), the Phosphatic Chalks give a truer idea of the original character of the rhizopod-fauna of the normal Chalk than can be gained by a study of the latter itself, the assemblage observed in the Taplow Chalk may be regarded rather as typical than accidental, and its mixed deep- and shallow-water character as possessing a wider significance than has hitherto been attached to it.

Among the many striking features of this Chalk there are, doubtless, some which plainly testify to the bathymetrical conditions

<sup>1</sup> A. Strahan, 'Natural Science' vol. i (1892) p. 286. See also Renard & Cornet, Bull. Acad. Roy. Belg. ser. 3, vol. xxi (1891) pp. 153-58.

<sup>2</sup> Mém. Soc. Géol. du Nord, vol. iv, 2 (1897) pp. 322-23.



prevailing during its formation. We have not, however, succeeded in recognizing them.

Some geologists may see satisfactory evidence of shallow water in

- (i) The signs of current-erosion, which, according to Sir John Murray & the late Prof. Renard,<sup>1</sup> is rarely operative at a greater depth than 100 fathoms, in open water.
- (ii) The abundance of bottom-living foraminifera—probably upwards of 60 per cent., according to Dr. W. F. Hume,<sup>2</sup> including some positively shallow-water forms.<sup>3</sup>
- (iii) The exceptional prominence of *Ostrea*, which gives the Brown Chalks an aspect reminiscent of certain Oolite limestones.
- (iv) The abundance of *Plicatula*.<sup>4</sup>
- (v) The occurrence of the gasteropod *Scalaria*.

Others will probably attach more importance to such indications of deeper-water conditions as

- (i) The extreme scarcity of bryozoa.<sup>5</sup>
- (ii) The absence of distinctively shallow-water lamellibranchs.
- (iii) The small size of most of the bottom-living foraminifera.
- (iv) The insignificant amount of terrigenous material, pointed out by Mr. Strahan.<sup>6</sup>
- (v) The small size, and predominant yellow or brown hue, of the phosphatic concretions common to the white and brown beds.<sup>7</sup>

Both lists could be greatly (and, we fear, unprofitably) extended.

The Senonian Phosphatic Chalks of Northern France, which the Taplow beds so closely resemble, are generally regarded as shallow-water accumulations by the geologists of that country, who refer to the accompanying erosion-features in terms which would, on this side of the Channel, be considered appropriate to the destructional phenomena of the shore.

But, whatever the bathymetrical conditions prevailing at Taplow in *Marsupites*-times—and the question is one into which we are not greatly tempted to enter—it may be doubted whether those conditions were of cardinal importance among the factors determining the abnormal character of the deposits at that spot. For the general aspect and disposition of the Upper Chalk in the South of England do not encourage the idea that the depth of water over the southern part of Buckinghamshire at that date was markedly different from that at other localities in Surrey, Hampshire, and Berkshire, less than 30 miles distant to the south-east, south, and west respectively, where the ordinary type of Chalk was in course of deposition.

The recognition of the rather wide range in time of the Taplow phosphates will necessitate some modification of those conceptions

<sup>1</sup> *Challenger-Reports*, 'Deep-Sea Deposits' 1891, p. 184.

<sup>2</sup> 'The Genesis of the Chalk' *Proc. Geol. Assoc.* vol. xiii (1894) p. 238.

<sup>3</sup> A. J. Jukes-Browne, 'The Cretaceous Rocks of Britain' vol. iii, *Mem. Geol. Surv.* 1904, pp. 372-73; and L. Cayeux, *Mém. Soc. Géol. du Nord*, vol. iv, 2 (1897) pp. 503-505.

<sup>4</sup> L. Cayeux, *op. cit.* p. 504; and A. J. Jukes-Browne, *op. cit.* p. 366.

<sup>5</sup> A. J. Jukes-Browne, *op. cit.* pp. 370-71.

<sup>6</sup> 'Natural Science' vol. i (1892) p. 287.

<sup>7</sup> *Challenger-Reports*, 'Deep-Sea Deposits' 1891, p. 392.

of their origin, which were influenced by the belief that their formation was a mere episode in the parochial history of a single zone. The persistence of the special conditions responsible for the deposition of an unusually-large proportion of calcium-phosphate around the site of the village of Taplow, from near the close of the *cor-anguinum*-age, throughout *Marsupites*-times, and possibly down to a later date, is a consideration which must be taken into account in attempting to frame a satisfactory theory. A 'temporary "change in the strength or direction of the local currents"' <sup>1</sup> may account for some of the phenomena, but is now clearly inadequate as an explanation of the Phosphatic Series as a whole.

#### V. STRUCTURAL RELATIONS.

At the date of publication of Mr. Strahan's account of this section (1891), the Phosphatic Chalk had not been proved to extend many yards beyond the limits of the Lodge pit. It is now known to occur over a wider area, for we have traced phosphatized foraminifera and other characteristic material in the pieces of chalk in the soil of the river-scarp, northwards, for a distance of 200 paces; and Mr. E. Lodge, the Agent of the Taplow-Court Estate, informs us that a brown chalk, similar to the rich phosphatic bands of the pit, was encountered in an excavation made for drainage-purposes in 1895, at Hill Farm, half a mile to the north-east.<sup>2</sup> These observations bear out Mr. Strahan's inference that the Phosphatic Chalk 'underlies a considerable part, if not all, of the outlier of Tertiary strata on which Taplow stands.'<sup>3</sup>

In the Hill-Farm digging, the Brown Chalk was proved at a depth of about 10 feet below the greensand-base of the Reading Beds; and Mr. Strahan records that, in the trial-shaft sunk in the rising ground above the Lodge Pit in 1891, the upper brown band (D) of that exposure occurred at a somewhat greater depth (20 feet) below that horizon.

The phosphatic deposits clearly lie near the upper limit of the Chalk, but we have been no more successful than Mr. Strahan in our search for them in the numerous exposures of beds occurring in a similar or lower position with regard to the Tertiaries in the surrounding country. All these exposures, however, so far as we have been able to ascertain, are in the zone of *Micraster cor-anguinum*, and now that we know the richer phosphatic beds of Taplow Court

<sup>1</sup> A. J. Jukes-Browne, 'The Cretaceous Rocks of Britain' vol. iii, Mem. Geol. Surv. 1904, p. 373 [quoting A. Strahan, in part].

<sup>2</sup> [Our apologies are due to Mr. Strahan for having overlooked the existence of a letter by him in the 'Geological Magazine' for 1895, p. 336, announcing this discovery, and giving more detailed information as to the succession of the beds in the excavation than we were furnished with. The letter is not mentioned in the general bibliography of the English Chalk in the Geological-Survey Memoir on the 'Cretaceous Rocks of Britain' vol. iii (1904). See Mr. Strahan's remarks in the discussion on the present paper, p. 493.—*H. J. O. W. & L. T., July 15th, 1905.*]

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 365.

to belong to a higher zone, the failure to detect them there is scarcely surprising.

Though the exact boundaries of the Phosphatic Series have still to be defined, its lateral range in certain directions can be shown to be small. Thus, along the higher part of the river-bluff which extends northward from the site of the Lodge Pit, there are some exposures of the normal type of Chalk, referable to the *Micraster cor-anguinum*-Zone, at distances ranging from a quarter to half a mile. The largest, and most distant, of these, known as the Root-House Pit, shows a fine section of the flinty beds, the top of which is probably not more than 15 feet below the base of the Eocene.

Near the railway-station, to the south-east, and at a distance of five-eighths of a mile, a similar chalk, capped by a remnant of the green, pebbly, 'bottom-bed' of the Reading Series, is shown in a pit worked for chalk and gravel.<sup>1</sup> Mr. Strahan, who notes the flinty character of the beds in these exposures, records a similar rock (also at the boundary of the Tertiary formations) seven-eighths of a mile to the north-north-east, in a section now all but destroyed, and yielding only chips of *Inoceramus*. On the south-west and north-east, the nearest pits are 1½ miles distant from the Lodge section and the Hill-Farm cess-pit respectively, and show *cor-anguinum*-beds of the usual type of the upper half of the zone, within a few feet of the junction with the Eocene strata. To the westward, the phosphates are cut off by the Thames Valley, while on the south and due eastwards their lateral range is quite unknown, as in those directions they are hidden, together with the rest of the Chalk, by thick sheets of river-drift and by the main body of the Tertiary deposits.

The incoming and disappearance of a mass of *Marsupites*- and *Micraster cor-anguinum*-beds of exceptional character to a thickness of at least 60 feet, between the normal *cor-anguinum*-Chalk and the Reading Beds, within a distance not greater (and possibly much less) than 1 mile along a roughly north-west to south-east line, indicate the existence of a marked unconformity between the Cretaceous and the Eocene rocks in this district. It is clear that these beds must either form a low boss, or eminence, rising above the early

<sup>1</sup> As Mr. Strahan has suggested (*loc. cit.*) that the chalk of this pit may possibly overlie the 'phosphatic zone,' we append a list of the fossils obtained from it by Mr. Rhodes (for the Geological Survey) and by ourselves:—

*Inoceramus Cuvieri*, Sow.

*Kingena lima*, DeFr.

\* *Pecten cretosus*, DeFr.

*Crania parisiensis* (?) DeFr.

\* *Rhynchonella reedensis*, Eth.

*Terebratulina striata*, Wahl.

*Entalophora madreporacea*, Goldf.

*Entalophora virgula*, Hag.

*Escharina inelegans*, Lonsd.

\* *Membranipora arborea*, d'Orb.

*Sparsicavea carantina*, d'Orb.

*Bourgueticrinus ellipticus*, Miller.

*Cidaris clavigera*, Koenig.

*Cidaris hirudo*, Sorig.

*Cidaris sceptrifera*, Mant.

*Echinocorys scutatus*, Leske, var. *ovatus*.

*Galerites albogalerus*, Leske (forma *pyramidalis*) (in a band).

\* *Metopaster Parkinsoni*, Forbes.

*Nymphaster* (?).

*Pseudodiadema fragile*, Wilts.

*Porosphæra patelliformis*, Hinde.

\* Indicates species in the Geological-Survey Collection.

The above is clearly a *Micraster cor-anguinum*-Zone assemblage.

Eocene plain of erosion marking the upper surface of the surrounding flinty *cor-anguinum*-Chalk, or occupy a depression below that plain.

Throughout the western part of the London Basin the observed inequalities at the junction of the Chalk and the Eocene, other than those due to 'piping' and post-Cretaceous folding and faulting, are of so slight and gentle a nature, that the former interpretation seems highly improbable; and an examination of the contours of the base of the Reading Beds around Taplow makes it practically certain that the Phosphatic Series lies in a depression—its top being planed flush with that of the enclosing older Chalk.

What is the nature of this depression? Is it (1) an inherent feature of the Chalk, or (2) a result of earth-movements occurring in the interval between the deposition of the highest beds of that formation and the lowest member of the Eocene System now existing in the district? If the contained beds were of the normal lithological character of the zones that they represent, their appearance in such a manner in a country where only lower beds are otherwise known to occur would, in most cases, be unhesitatingly ascribed to folding or faulting. In view of their exceptional features, however, so simple an explanation should not be lightly accepted. The data which are at present available seem hardly sufficient for the solution of this problem, and we have little more than general probabilities to guide us.

(1) On the assumption that the hollow or basin in which the Phosphatic Series of Taplow lie is a congenital feature of the Upper Chalk, it may reasonably be ascribed, either to (a) irregular deposition, or to (b) intra-formational erosion—each of a kind involving a sudden and local decrease in the thickness of one group of beds, with a corresponding downward deflection of the base of the succeeding group. In the Phosphatic Series, as exposed at Taplow Court, there is, as we have seen, some indication of the operation of both processes; but no loss which that Series has thereby sustained, however great, will account for its presence apparently in the midst of other strata. It is a local reduction in the thickness of these older rocks (namely, the main mass of the flinty *Micraster cor-anguinum*-beds), by thinning or by erosion antecedent to the deposition of the Phosphatic Group, that is demanded on the present assumption.

The amount of the supposed loss cannot, of course, be adequately gauged until the maximum depth of the trough is known, but it is clearly not less than the thickness of the beds exposed at the Lodge-Pit section *plus* the few feet of chalk lying between the Eocene base and the top of the pit, that is, about 65 feet. The maximum possible distance in which this loss takes place in the rocks to the south-east of the Lodge section is fixed by the Railway-Station pit, which shows the Eocene deposits in contact with the *Micraster cor-anguinum*-Beds, at five-eighths of a mile; while, so far as can be judged from the less complete evidence of the exposures in the river-scarp, the loss is incurred in an even smaller distance on the north.

(a) Though the zone of *Micraster cor-anguinum* is, of all the subdivisions of the Upper Chalk in the South and South-East of England, the least liable to great fluctuation in thickness; though the monotonous character of its fauna argues a stability in the physical conditions during the deposition of its constituent beds which would be entirely in keeping with this uniformity, yet the *à-priori* probabilities of its attenuation in this neighbourhood are but little smaller than those of an exceptionally-marked shrinkage in the succeeding zone—such as we know to occur. But, if the *Marsupites*-Beds, by their small development at the Lodge section, serve as a precedent for zonal thinning in the Taplow area, they do not serve as a precedent for rapid zonal thinning, for their apparent isolation leaves us entirely in doubt as to the rate of lateral attenuation in their case; and the possibility of the *Micraster cor-anguinum*-Zone suffering so large a reduction as that above indicated within so small a space—a reduction, moreover, unsignalized by appropriate changes in the character of the higher beds of that zone in the vicinity—is one which, we imagine, will recommend itself to few who are familiar with the Chalk.

(b) The alternative supposition under this heading, namely, that the trough was formed by submarine erosion towards the close of *cor-anguinum* times, and refilled with the latest beds of that zone and the more richly-phosphatic *Marsupites*-sediments, finds some support in the mode of occurrence of certain bodies of Phosphatic Chalk in Northern France, for instance, Hardivillers (Oise), Sénercy, and Hem-Monacu (Somme), which have been shown, or inferred, to occupy eroded hollows. The evidence of the erosive origin of the phosphate-basins in that country is not always as complete as one could wish; and some of the phenomena attributed to intra-Cretaceous ‘ravinement’ seem equally explicable by other processes. Setting aside the doubtful cases, however, there remain a number of others in which the basin almost certainly owes its existence to the scouring action of currents upon the Upper Cretaceous sea-bed.

Now, in the French phosphate-workings the bored and hardened floor (‘craie blanche durcie, à surface vernissée’) of the lowest bed of rich Phosphatic Chalk is usually regarded as the downward limit of the erosion referred to, that is to say, as the bottom of the phosphate-trough; and, during the earlier stages of our examination, we were much disposed to view the corresponding feature at the top of the *Micraster cor-anguinum*-Beds (A) of the Taplow-Court section in the same light. When, however, it became apparent that the greater part of the (A) beds were not only distinct from those visible at a similar, or at any other, depth below the base of the Eocene deposits in the adjoining country, but in addition so intimately allied to the overlying Chalk as fully to warrant their inclusion in the Phosphatic Series, that idea was abandoned. As already pointed out, the occurrence of erosion-phenomena within the Phosphatic Series has no direct bearing on the problem of the mode of occurrence of the latter as a whole; and if that Series, as we define it, lies in an eroded hollow, the unconformity marking the bottom of

the hollow must be situated somewhere below the floor of the Lodge pit. But the incoming of flint-bands, accompanied by a change in the texture of the Chalk, near the visible base of Division (A) at that spot, strongly suggests that the Phosphatic Series is there passing down into the normal Chalk shown in all the other sections in the district. Unless appearances are deceptive, and an unconformity actually occurs within the flinty beds lower down, the hypothesis of the erosive origin of the trough must be rejected.

(2) Turning to the second assumption—that the trough has a late, or post-Cretaceous, tectonic origin—we may pass over (*a*) the supposition of faulting, as being neither supported nor opposed by a single scrap of evidence, to consider (*b*) the possibility of synclinal folding.

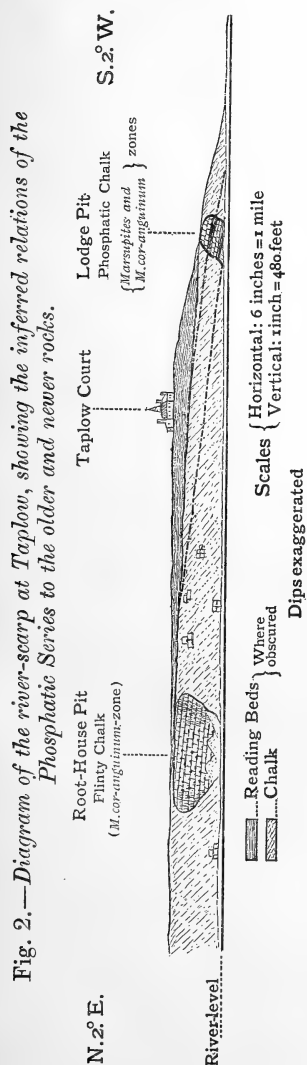
So far as we are aware, no undoubted instance of pre-Tertiary (in this case, more strictly, pre-Reading) folding, save of the broad and gentle type better described as regional warping, has yet been recorded in the Chalk of the London Basin: but we attach little value to this as an *à-priori* argument against the occurrence of such at Taplow; for until the Chalk of that area has been carefully zoned, folds of insufficient strength to produce a distinct angular unconformity between that formation and the Eocene, in the limited junction-exposures usually available, are not likely to be detected. The recognition of disturbances of this date in the Chalk of the Hampshire Basin<sup>1</sup> and of Northern France,<sup>2</sup> and our own observations in Berkshire and Wiltshire, lead us to anticipate that the mapping of the zones of the Upper Chalk will reveal the existence, within the London Basin, of many flexures which either do not affect the Eocene deposits, or affect them in a less degree.

The evidence in favour of the synclinal origin of the Taplow Phosphate-basin mainly rests on the inclination of the beds in the Lodge section, and in the Root-House Pit, on the north. In the former excavation this is approximately to the south-east, at angles of 5° to 8°; in the latter, to the south-south-east, or thereabouts, at 6° to 8°. These dips are unusually high for the district, and, so far as we have been able to ascertain, do not agree with the inclination of the base of the Eocene deposits in the vicinity, which appears to be a gentler one to the south-east. The crest-line of the river-scarp, which practically coincides with the junction of the Chalk and the Reading Beds on the west side of the Taplow outlier, having a southward decline of about 1½° between the two excavations, the strong southern element in the much higher true dip of the Chalk at the Root-House Pit, would, if persistent, suffice to bring in a considerable thickness (not less than 100 feet)

<sup>1</sup> A. J. Jukes-Browne, 'Cretaceous Rocks of Britain' vol. iii, Mem. Geol. Surv. 1904, p. 45; and C. Barrois, 'Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irlande' Mém. Soc. Géol. du Nord, vol. i (1876) p. 113.

<sup>2</sup> See Marcel Bertrand, 'Sur la Continuité du Phénomène de Plissement dans le Bassin de Paris' Bull. Soc. Géol. France, ser. 3, vol. xx (1892) p. 150; and H. Parent, 'Notes supplémentaires sur les Plis du Nord de l'Artois' Ann. Soc. Géol. du Nord, vol. xxi (1893) pp. 102-104.

of higher beds of that formation below the Eocene strata at the site of the Lodge section (see fig. 2).



The few small exposures, and the not very trustworthy surface-indications in the intervening ground, seem to show the decrease in the proportion of flints, and the gradual incoming of phosphatic material from north to south, which are to be expected in a normal ascending sequence.

In the pit near Taplow Station, to the south-east, also, there are signs of some disturbance, but the dips are too variable to afford any indication of its nature or general tendency. In no other section seen by us in this district does the Chalk exhibit a definite inclination; and it is to be supposed that the Taplow flexure is either a very local one of the periclinal type, or that its influence is confined to the rocks of a narrow belt of country.

The structural features of the Lodge and adjoining, more northern, exposures indicate a synclinal axis, with a direction roughly north-east to south-west, lying to the south-east (and probably within 500 yards) of the first-mentioned exposure.

As the age of this flexure cannot be satisfactorily demonstrated from the existing data, its bearing on the problem of the Phosphate-basin remains doubtful. So little is yet known concerning the late Cretaceous and early Eocene folds in the South of England, that an appeal to them to explain the occurrence of a small deposit belonging to a class notoriously irregular both in its distribution and in its relations with other rocks, may not be viewed with much favour. In the very infrequency of such deposits in the

Chalk of this country, some may see an argument for the existence of a more intimate relationship between the Taplow Phosphates and the trough in which they lie, than that usually subsisting between a given group of sediments and the flexures determining its attitude as a rock-mass.

In the present instance, however, rarity is a quality to which it is easy to attach too much importance. When regarding the Taplow phosphates as a whole, one instinctively contrasts them with the normal Chalk of the adjoining country, and the dominant impression received is that of their singularity. But it must be remembered that they are of a different age from the rocks with which they appear to be so intimately associated, and form a relic of a sheet of newer beds once extending over the district. Although the nature of those vanished beds is not to be safely inferred from the sample that remains, it is nevertheless open to question whether the Taplow phosphates may not present a type of deposit which was fairly common in the contemporary sediments of this part of the country. In this connection, it is important to note that the Phosphatic Chalks found at the same horizon, and at higher horizons, in the Upper Cretaceous rocks of Northern France and Belgium, though nearly all, individually, of very limited extent, commonly occur in groups scattered over tracts of country many square miles in area. The Taplow example may well be a member of such a group; in which case other members may still exist in the district—possibly beneath the main mass of the Eocene deposits to the south and east. A complete demonstration of their absence would not, necessarily, dispose of the possibility of their former existence; for, on the supposition that the trough containing the only-known example is due to folding, a plausible reason for the special preservation of that deposit is at hand. The synclinal flexure which carried it below the general level of the contemporary strata, and placed it in its present anomalous position among older rocks, also carried it below the plane which was subsequently adopted as the downward limit of early Tertiary erosion.

## VI. SUMMARY OF CONCLUSIONS.

(i) The Phosphatic Chalk of Taplow, exposed at the South Lodge of Taplow Court, is referable to the zones of *Micraster cor-anguinum* and *Marsupites testudinarius*.

(ii) The two, more richly-phosphatic, Brown Beds, distinguished in the foregoing account by the letters (B) and (D), belong to the latter zone, and represent the lower parts of the *Urtacrinus*-Band and of the *Marsupites*-Band, respectively, in a much attenuated condition.

(iii) The distribution, numerical proportion, and, to some extent, also the morphological character of the macroscopic fossils of this Chalk, are exceptional.

(iv) A part, at least, of the phosphatized material entering into the composition of the deposit has acquired its distinctive mineralogical character on the spot.

(v) So far as can be ascertained from existing data, the Phosphatic Chalk is confined to a small tract of country measuring less than  $3\frac{1}{2}$  miles from north-east to south-west, and less than 1 mile from north-west to south-east.



(vi) It occurs as an intercalation between the normal (*Micraster cor-anguinum*) Chalk and the Lower Eocene (Reading) Beds; and occupies a structural trough which coincides with, and is probably due to, a synclinal flexure.

Our thanks are due, in the first instance, to Mr. W. H. Grenfell, M.P., for kindly permitting us to examine the sections in his grounds, and to Mr. E. Lodge, his agent, for information bearing on the lateral range of the Phosphatic Chalk.

We are very deeply indebted to Dr. A. W. Rowe, who has not only most kindly placed his vast knowledge of the English Chalk-zones at our service, but has also enabled one of us, by his well-known hospitality, to compare the Taplow fossils with the extensive series from the same and from other horizons of the normal Chalk in his collection. But for his guidance, we should probably have fallen into the old error with regard to the species of *Actinocamax* occurring in the upper part of the Lodge section.

We also gratefully acknowledge the assistance received from Messrs. A. J. Jukes-Browne, G. C. Crick, and H. A. Allen, with the first of whom we have had the advantage of discussing some of the stratigraphical and tectonic problems presented by the rocks in the Taplow district.

#### DISCUSSION.

Mr. STRAHAN expressed his sense of the value of the zonal work done by the Authors. It supplied a distinct deficiency in our knowledge of a district. At the time of his examination of the pit, no distinction had been recognized in this country between *Actinocamax* (then known as *Belemnitella*) *quadratus* and *A. granulatus*. The correlation of the Taplow Chalk with the *Marsupites*-Zone, which he had adopted from the London Memoir, had been proved to be substantially correct, but the identification of a lower zone in the pit was a new and important point. The Authors' identifications seemed to imply a considerable attenuation of some of the zones, as exhibited in the Lodge Pit—a most interesting circumstance, taken in connection with the occurrence of phosphatized deposits and other evidences of arrested sedimentation.

The second pit, referred to as proving the existence of phosphatic chalk, had been described by him in the 'Geological Magazine' for 1895. There a band of this material, 2 feet thick, was separated from the Tertiary base by 8 feet of Chalk, as compared with 18 feet at the Lodge Pit. This suggested an unconformity; but the overlap appeared unusually rapid, in view of the approximate parallelism of the Tertiary deposits and the Chalk in the neighbouring parts of England. He had not grasped the evidence on which a synclinal structure was attributed to the Taplow Chalk. He desired to congratulate the Authors on a piece of useful work, carried out under considerable difficulties.

Dr. A. W. ROWE stated that, when the Fellows had been able to read the paper, they would find that an exceptionally-difficult

and puzzling piece of work had been carried out with a marked degree of skill and care. He felt that the results obtained were a triumph for the zonal method and for scientific collecting. The failure of Mr. Strahan and Mr. Jukes-Browne to obtain any zonal results that carried conviction with them was due to inadequate collecting.

The speaker noted the fact that, although the two divisions of the *Marsupites*-Zone were so abnormally thin, the zoological sequence was perfect, and that *Actinocamax verus* was associated with *Uritacrinus* and *A. granulatus* with *Marsupites*. He remarked on the wonderful number of the belemnites found in this small thickness of Chalk, and stated that no similar thickness of Chalk in his experience had yielded so great a quantity. The belemnites showed progressive 'reefing' of the alveolar cavity as the beds were taken in an ascending series; but there was no example, even in the highest beds, that could be truly called *Actinocamax quadratus*. *Echinocorys* here exhibited quite an abnormal facies; for the series is notably dwarfed, and as a whole does not exhibit the shape-variations which are so distinctive of horizons in the South of England. The pyramidal shape-variation always found in the *Marsupites*-Zone was present at that level, but was singularly rare.

In conclusion, the speaker pointed out that the Authors had understated the difficulties of the work. He had seen all the fossils, and one of the chief difficulties lay in their fragmentary state and poor preservation. He had, however, no hesitation in stating that, in his opinion, the horizons fixed by the Authors were accurate, for they were based on definite zoological evidence.

Mr. OSBORNE WHITE, in reply to Mr. Strahan, outlined the evidence for the synclinal origin of the Taplow Phosphate-basin, to which, and to some other important points, the small space of time available for the reading of the paper had permitted only the briefest allusion. On Mr. Treacher's behalf, and his own, he thanked the previous speakers for the appreciative tone of their remarks.

24. *THE MARINE BEDS in the COAL-MEASURES of NORTH STAFFORDSHIRE.* By JOHN T. STOBBS, F.G.S. *With NOTES on their PALÆONTOLOGY* by WHEELTON HIND, M.D., B.S., F.R.C.S., F.G.S. (Read January 4th, 1905.)

## [PLATES XXXIV-XXXVI.]

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## I. INTRODUCTORY REMARKS.

THE North-Staffordshire Coalfield offers exceptional facilities for the study of Coal-Measure geology. It is remarkably rich in deposits of coal, ironstone, and marl, which are being worked by means of a comparatively-large number of mines and quarries; and, by reason of the excessive folding and faulting of the Measures, the whole sequence is exposed within a moderate area. The number of these exposures is further increased by the shaft-sinkings and cross-measure drifts which are rendered necessary by the disposition of the strata, and are constantly in progress in some part of the district in the process of mining the different beds. Each of these operations, therefore, not only reveals a section of the strata, but also provides a large quantity of material for search and examination. In order, however, to reap the fullest benefit from such opportunities, it is necessary to inspect the excavated débris almost day by day, so that the stratigraphical position of each fossiliferous band may be located *in situ*, with exactness. It is obvious that this can only be performed by local workers; and, during the past six years, I have taken advantage of these opportunities for minute and careful examination of the individual beds of the Coal-Measures, chiefly with the purpose of establishing a more satisfactory correlation of the seams in the different areas of the Coalfield. Fortunately, the work has added to our knowledge of the prevalence of marine conditions during the period of deposition in the Midlands of those Measures which contain the most valuable coal-seams, and were for that reason denominated by Ramsay 'the true Coal-Measures.'

During that period marine conditions were not only more frequent than is generally supposed; but, what is of the highest importance in stratigraphy, they are proved by the persistence of the beds to have been practically co-extensive with the Coalfield.

## II. THE SIGNIFICANCE OF MARINE HORIZONS IN THE COAL-MEASURES.

The occurrence of marine bands in the Coal-Measures has hitherto been used for the purposes of (*a*) theoretical subdivision or grouping (as distinct from mapping) and (*b*) identification of coal-seams.

### (*a*) Subdivision of the Coal-Measures.

By the recognition on the part of the earlier workers (notably E. W. Binney and John Phillips) of the marine fossils in beds overlying the Bullion Coal of Lancashire and the Hard Bed of Yorkshire; and later, thanks to the work of J. W. Salter in South Wales, and to the influence of Warington Smyth, and more especially of Prof. E. Hull, the lower portion of the Coal-Measures has come to be regarded as being essentially marine in character, and on that account distinguishable from the overlying or so-called 'Middle' Series. Indeed, the well-known grouping of the Coal-Measures into Lower, Middle, and Upper Series was chiefly based on the respectively marine, estuarine, or freshwater character of their mollusca.

This classification which, confessedly, was mainly adopted for convenience of description,<sup>1</sup> has, through lack of definition, come to be used in the most irregular way by various writers on Coal-Measure geology, and few practical results are due to its adoption. Its weakness is at once revealed when we desire to trace the subdivisions from one coalfield to another, for then it is discovered that they are incapable of being mapped. Hence, it is of little service to the mining engineer, who, after all, has the strongest claim to utilize the results of the scientific investigation of the Coal-Measures. The confusion that may arise from its application is nowhere more signally shown than by the inclusion of the Pennystone of Coalbrookdale and of South Staffordshire in the Lower or Gannister Series, because of the marine character of the fossils found at that horizon.<sup>2</sup> This error was first definitely pointed out by Mr. R. Kidston in 1893, as a result of his study of the fossil flora of the Coal-Measures of South Staffordshire.<sup>3</sup>

A reference to fig. 1 (p. 499) will show that recurrences of marine conditions obtained practically throughout the 'true Coal-Measure' period, some of which were marked by an exceedingly-rich fauna. These recurrences may be shown to serve a more useful purpose than even that of classification, namely, the recognition of individual horizons over wide areas.

<sup>1</sup> E. Hull, 'The Geology of the Country around Prescott, Lancashire' Mem. Geol. Surv. 3rd ed. (1882) p. 2.

<sup>2</sup> E. Hull, Quart. Journ. Geol. Soc. vol. xxxiii (1877) pp. 629-30.

<sup>3</sup> Proc. Roy. Phys. Soc. Edin. vol. xii (1892-94) p. 187.

## (b) Identification and Correlation of Coal-Seams.

Owing to the variation in the characters of coal-seams with respect to thickness, quality of coal, nature of roof, and presence of dirt-bands in the coal, the seam-nomenclature in all our coalfields, when referred entirely to these characters, is more or less conflicting. When these physical difficulties in correlation are artificially reinforced by the inducement to alter the name of a coal-seam for commercial purposes, we may to some extent understand the existing confusion. Nevertheless, without any aid from palæontology, the correlation of seams that has been accomplished by mining-engineers is remarkably accurate. In some measure, this is due to the fact that the coal-seam itself is a stratum which implies special conditions of deposit, and, viewed in this aspect, affords evidence almost as valuable as that of palæontology for the purposes of stratigraphy. All the work of correlation of seams has been left to the mining-engineer, whose profession demands a much more detailed and exact knowledge of the Coal-Measures than that obtainable from the groups above mentioned, even could such groups be traced throughout the coalfields.

It seems, therefore, surprising that, for this work of identification of coal-seams, the aid to be derived from marine bands should not have been more fully utilized. In a series of measures which are largely of terrestrial and freshwater origin, the presence of marine bands denotes singularity of conditions of deposit, which constitutes them ideal horizons for the purposes of stratigraphy. The dissimilarity, between the freshwater and the marine mollusca most commonly found fossil in the Coal-Measures, is so marked that they can be readily distinguished by those totally ignorant of palæontology. Phillips long ago pointed out the peculiar interest of these beds, and after describing the occurrence of one of them over an area embracing the vicinities of Leeds, Bradford, Halifax, Penistone, and Sheffield, stated that

‘The uniform occurrence of these pectens and ammonites [*Pterinopecten* and *Goniatites*] through so wide a range, over one particular thin bed of coal . . . is one of the most curious phenomena yet observed concerning the distribution of organic remains, and will undoubtedly be found of the highest importance in all inferences concerning the circumstances which attended the production of coal.’<sup>1</sup>

This line of research, however, has not been followed, and, although in most of our coalfields marine beds have been found at isolated localities, so far as the writer is aware no systematic effort has been made to trace them throughout those coalfields. In fact, their true significance in Coal-Measure stratigraphy seems to have been misapprehended, or subordinated to that of the workable seams of coal and ironstone. When these seams cease to be workable, by pinching-out or otherwise deteriorating, it is not uncommon for their names to be given to a different bed, which may occur about

<sup>1</sup> Encyclopædia Metropolitana, vol. vi (1845) art. on Geology, p. 590.

that horizon and has so thickened as to become a payable deposit. Illustrations of this method and its resulting confusion may be cited from all our large coalfields. In contradistinction, marine beds enable correlation to be made with exactness at specific horizons, and form admirable datum-lines for the practical geologist and the mining-engineer. The general impression, however, as to their utility is that their fossils

'come from particular beds, of small number, of very trifling thickness, and in all but one case [presumably the Hard Bed] of very little constancy.'<sup>1</sup>

The number of these beds is much greater than was known at the time when the passage just quoted was written, and, although they are very thin, that is of no moment if only they be persistent. Jukes, referring to the marine bed in the upper portion of the Pennystone measures of South Staffordshire, states that it is 'confined to a very small district between Oldbury and Portway.'<sup>2</sup> On the contrary, it will be shown later that this particular bed extends over a very wide area, but sufficient has now been said in explanation of the general attitude with respect to the importance of these beds.

Remembering what marine horizons have done for the Hard Bed of Yorkshire and the Bullion Coal of Lancashire, and what our experience of them in North Staffordshire has taught us, there can be no doubt of their excellence as index-beds. If they be used in the way which I have suggested,<sup>3</sup> namely, by selecting them as main lines for the subdivision of the measures in a coalfield, while the intervening beds are traced by other mollusca, entomostraca, etc., the work of correlation will be placed on a sound and scientific basis, and the aid of geology will be more often sought in the everyday problems which confront those who are engaged in the practical work of winning stratified mineral deposits.

### III. THE MARINE HORIZONS IN THE NORTH-STAFFORDSHIRE COALFIELDS.

The known horizons at which marine fossils occur in the Coal-Measures of North Staffordshire are:—

1. Roof of the Bay or Lady Coal.
2. The Priorsfield Ironstone-Measures.
3. The Speedwell and Nettlebank Bed. } Below the Twist or Gin-Mine Coal.
4. The Florence Colliery-Band. }
5. Above the Moss Coal.
6. Roof of the Single Two-Feet Coal or Moss Cannel.
7. Above the Seven-Feet Banbury Coal.
8. The Weston-Sprink Bed.
9. Below the Four-Feet Coal of Cheadle.
10. The Knypersley Marine Band.
11. Near the Crabtree Coal (three horizons).

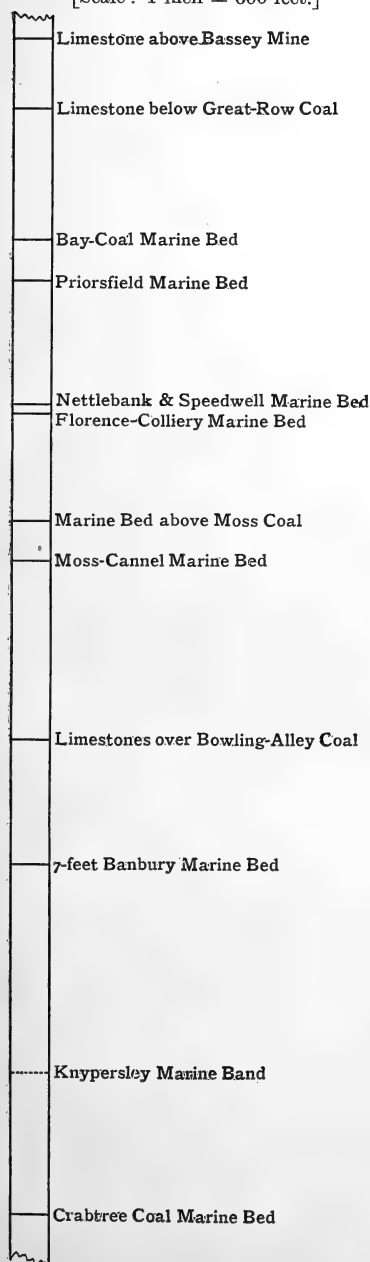
<sup>1</sup> L. C. Miall, in 'Coal: its History & Uses' 1878, p. 153.

<sup>2</sup> 'The South Staffordshire Coalfield' Mem. Geol. Surv. 2nd ed. (1859) p. 58.

<sup>3</sup> Trans. Inst. Min. Eng. vol. xxii (1901-1903) p. 234.

Fig. 1.—*Vertical section illustrating the succession of the marine horizons in the Coal-Measures of North Staffordshire.*

[Scale : 1 inch = 600 feet.]



Their relative positions are illustrated in fig. 1, a glance at which will show that they occur at intervals remarkably convenient for the purpose of subdivision of the measures; and, when supplemented by the existence of entomostracan limestones, they ensure complete correlation of the Coal-Measures, with a precision such as to satisfy the needs of commercial men.

The places where these horizons have been traced are shown in Pl. XXXIV (facing p. 514), which is an outline-map whereon the following localities are represented by the numerals given in the list :—

1. Silverdale, No. 16 Pit.
2. Leycett Colliery.
3. Hayeswood Colliery.
4. Minnie Pit, Halmerend.
5. Talk-o'-th'-Hill Colliery.
6. Birchenwood, No. 18 Pit.
7. Chell Colliery.
8. Norton Colliery.
9. Nettlebank Sinking.
10. Sneyd Colliery.
11. Slippery-Lane Pit, Hanley.
12. Berry Hill, Deep Pit.
13. Weston Sprink.
14. Meir-Hay Colliery.
15. Speedwell Colliery.
16. Priorsfield.
17. Foley Colliery.
18. Longton-Hall Colliery.
19. Florence Colliery.

The thicknesses of the beds in all sections are measured perpendicularly to their bedding-planes, unless the contrary is stated.

#### (1) Roof of the Bay or Lady Coal.

This bed was discovered by Mr. John Ward, in 1863, at the Foley Colliery, near Longton (17 in Pl. XXXIV), overlying the Bay Coal at that place; and, although it had been passed through many

times, it escaped recognition until 1901, when it was found *in situ* by Mr. E. P. Turner and myself in the roof of the Lady Coal, at Chell Colliery (7 in Pl. XXXIV)—the distance between the two collieries being about 6 miles. The Lady Coal occurs about 48 feet above the Knowles or Winghay Coal, which is a well-known seam in North Staffordshire. This marine horizon, then, proves the identity of the coal which receives two names in different localities.

The exact position of the bed at Chell Colliery is recorded in the following section :—

	Thickness in feet inches.	
Light-grey shale, with marine fossils .....	0	2
Black fissile shale .....	1	3
LADY COAL.....	2	4
Underclay, with <i>Stigmaria</i> .		

The following fossils have been obtained at these two localities some of them in a beautiful state of preservation :—

[v.a. = very abundant ; c. = common.]	FOLEY COLLIERY. No. 17 (Pl. XXXIV).	CHELL COLLIERY. No. 7 (Pl. XXXIV).	
<i>Ctenodonta</i> sp. ....	*		
<i>Pterinopecten papyraceus</i> (Sow.) .....	*	*	
<i>Lingula mytiloides</i> , Sow. ....	*	*	v.a.
<i>Orbiculoidea nitida</i> (Phill.) .....	*	*	c.
<i>Productus</i> sp. ....	*		
<i>Spirifer</i> sp. ....	*		
<i>Dimorphoceras Looneyi</i> (Phill.) .....	*		
<i>Discites falcatus</i> , Sow. ....	* (named by J. W. Salter.)		
<i>Gastrioceras Listeri</i> (Mart.) .....	*		
<i>Orthoceras</i> sp. ....	*		
<i>Macrocheilus</i> sp. ....	*		
Fish-remains .....	...	*	
<i>Beyrichia arcuata</i> , Bean .....	...	*	

## (2) The Priorsfield Ironstone-Measures.

In 1859, it was discovered by W. Molyneux and Mr. John Ward that the brown roof-shale of this ironstone contained a marine fauna. The only locality where this has been found is at Priorsfield, Longton (16 in Pl. XXXIV), and *Lingula mytiloides*, Sow., and *Orbiculoidea nitida* (Phill.) were obtained, both very abundantly.

### The Marine Beds below the Twist or Gin-Mine Coal.

These remarkable horizons were, in all probability, referred to by S. Lucas, who in 1865 recorded them as having been discovered by a young man named Amison, of Longton,<sup>1</sup> although one of them

<sup>1</sup> Geol. Mag. 1865, p. 570.



was described by him as overlying the Gin Mine. They were, however, independently discovered by Mr. John Ward, F.G.S., and our previous knowledge of the wonderful fauna of these beds is due to the patient work of that observer.

### (3) The Speedwell and Nettlebank Marine Bed.

Fortunately, this important horizon was carefully worked in 1865 at Speedwell Colliery, near Longton (15 in Pl. XXXIV) and later at Meir Hay, near Longton (14 in Pl. XXXIV) by Mr. John Ward. It was not again observed until March 9th, 1903, when I discovered it at the Nettlebank sinking, near Smallthorne (9 in Pl. XXXIV), although during that interval it also must have been passed through a great number of times. In June 1904, by the aid of a grant from the British Association, the outcrop of the bed was ascertained near Smallthorne, and its position mapped. This horizon affords exact proof of the identity of the Twist Coal of the Norton area with the Gin Mine of the Longton area—these places being about  $4\frac{1}{2}$  miles apart.

At Speedwell Colliery the marine horizon was met with about 90 feet below the Gin Mine, and at Nettlebank it was found about 54 feet below the Twist Coal.

Beyond comparison this is the most important marine deposit in the Coalfield: it is remarkably rich in fossils, with respect both to number of species and to number of individuals. It marks singular extensions of the range of many forms, for its position is seen to be in the upper portion of the 'true Coal-Measures.' Some of the fossils are new to science, and some belong to genera new to Britain.

After I had informed a few of my friends of the existence of a large quantity of material at Nettlebank, I received their valuable aid in collecting, and the following list is the result of their joint labours. In this connection, special acknowledgment must be made of the services of Dr. Wheelton Hind and Messrs. John Ward, W. Lockett, J. Pringle, A. E. Cooke, and E. P. Turner.

[c. = common; n.r. = not rare.]	SPEEDWELL.	NETTLEBANK.	
	No. 15 (Pl. XXXIV).	No. 9 (Pl. XXXIV).	
<i>Ctenodonta levirostris</i> , Portl. ....	*	*	c.
<i>Ctenodonta undulata</i> .....	...	*	
<i>Edmondia</i> sp. ....	*	*	
<i>Nucula gibbosa</i> , Fleming .....	*	*	c.
<i>Nucula oblonga</i> , M'Coy .....	...	*	
<i>Nuculana acuta</i> (Sow.) .....	...	*	n.r.
<i>Nuculana Sharmani</i> , R. Eth. fil. ....	...	*	
<i>Posidoniella lævis</i> (Brown) .....	*	*	
<i>Posidoniella sulcata</i> , sp. nov. ....	*	*	c.
<i>Pseudamusium fibrillosum</i> (Salt.) .....	...	*	

[a. = abundant; c. = common; r. = rare; n.r. = not rare; v.c. = very common.]	SPEEDWELL. No. 15 (Pl. XXXIV).	NETTLEBANK. No. 9 (Pl. XXXIV).	
<i>Pterinopecten papyraceus</i> (Sow.) .....	...	*	a.
<i>Schizodus antiquus</i> , Hind .....	*	*	
<i>Solenomya primæva</i> , Phill. ....	*	*	
<i>Syncyclonema carboniferum</i> , Hind .....	*	*	n.r.
<i>Ambocælia carbonaria</i> , sp. nov. ....	...	*	
<i>Chonetes laguessiana</i> , mut. θ de Kon. ....	*	*	a.
<i>Langula mytiloides</i> , Sow. ....	...	*	c.
<i>Orbiculoidea nitida</i> (Phill.) .....	...	*	r.
<i>Productus anthrax</i> , sp. nov. ....	*	*	
<i>Seminula ambigua</i> (Sow.) .....	...	*	c.
<i>Dimorphoceras Gilbertsoni</i> (Phill.) .....	...	*	v.c.
<i>Ephippioceras costatum</i> , Foord .....	...	*	r.
<i>Gastrioceras carbonarium</i> (L. von Buch) ...	...	*	
<i>Glyphioceras bilingue</i> ? (Salt.) .....	...	*	
<i>Glyphioceras diadema</i> , Beyr. ....	...	*	
<i>Glyphioceras micronotum</i> (Phill.) .....	...	*	
<i>Glyphioceras Phillipsi</i> , Foord & Crick .....	...	*	
<i>Glyphioceras reticulatum</i> (Phill.) .....	...	*	
<i>Nautiloid</i> , sp. nov. ....	...	*	
<i>Orthoceras</i> aff. <i>asciculare</i> , Brown .....	...	*	n.r.
<i>Orthoceras</i> sp. ....	*	*	c.
<i>Pleuromutilus armatus</i> (Sow.) .....	...	*	n.r.
<i>Pleuromutilus costatus</i> , sp. nov. ....	...	*	n.r.
<i>Solenocœilus</i> aff. <i>cyclostomus</i> (Phill.) .....	...	*	
<i>Stroboceras sulcatum</i> .....	...	*	
<i>Tennocheilus concavus</i> (Sow.) .....	...	*	
<i>Bellerophon</i> ( <i>Euphemus</i> ) <i>Urei</i> , Flem. ....	...	*	
<i>Loxonema acutum</i> , de Kon. ....	*	*	n.r.
<i>Macrocheilina</i> sp. ....	*	*	
<i>Naticopsis brevispira</i> (de Ryckholt) .....	...	*	
<i>Raphistoma radians</i> , de Kon. ....	...	*	n.r.
<i>Turbonellina formosa</i> , de Kon. ....	...	*	
<i>Archæocidaris</i> sp. ....	...	*	v.a.
Crinoid-ossicles .....	...	*	
<i>Acanthodes Wardi</i> , Egert. ....	...	*	n.r.
<i>Cœlacanthus elegans</i> , Newb. ....	...	*	
<i>Edestus triserratus</i> , Newton. (New species.) .....	...	*	
<i>Elonichthys Egertoni</i> (Ag.) .....	...	*	
<i>Listracanthus Wardi</i> , Woodw. (New species.) .....	...	*	
<i>Megalichthys Hibberti</i> , Ag. ..	...	*	c.
<i>Megalichthys intermedius</i> , Woodw. ....	...	*	
<i>Orodus</i> ? (small) .....	...	*	
<i>Platysomus parvulus</i> , Ag. ....	...	*	n.r.
<i>Pleuroplax Rankinei</i> , Ag. ....	...	*	
<i>Rhizodopsis sauroides</i> (Will.) .....	...	*	
<i>Sphenacanthus</i> ? (teeth) .....	...	*	
<i>Spirorbis</i> , sp. ....	...	*	
<i>Lepidostrobos</i> aff. <i>Geinitzii</i> , Schimp. ....	...	*	
Plant-remains .....	...	*	

The fossils in the foregoing list were not indiscriminately mingled together; and one object of the examination of the outcrop of the bed near Smallthorne was to ascertain the relations of the separate faunal divisions, with the following result:—The upper layer contained *Lingula mytiloides* and, very sparingly, *Orbiculoidea nitida*: these forms being scattered through the dark-grey shale overlying an earthy limestone, containing (according to Dr. W. Pollard) some magnesia and ferrous carbonate. In this limestone, *Chonetes laguesiana*, *Seminula ambigua*, and *Nucula gibbosa* were the commonest forms, and associated with them were *Productus semireticulatus*, *Pleuromutilus armatus*, *Pl. costatus*, *Ephippioceras costatum*, *Raphistoma radians*, and rarely *Archæocidaris* sp. It was in this limestone that Mr. J. Pringle found *Edestus triserratus*.<sup>1</sup>

In a thin, but highly-fossiliferous layer, underlying the above-mentioned limestone, the following forms were abundant:—*Archæocidaris* sp., *Ctenodonta levirostris*, *Loxonema* sp., *Orthoceras pygmaeus*; while associated with them in the shale were:—*Pseudamusium fibrillosum*, *Nuculana acuta*, *Synclonema carboniferum*, *Turbonellina* cf. *formosa*, and *Bellerophon* (*Euphemus*) *Urei*. At the base of the marine bed *Pterinopecten papyraceus* and *Posidoniella sulcata* were obtained in fair abundance.

In the dark shale numbers of large ‘bullions’ were found: they were usually flattened in shape; their specific gravity ranged from 2·79 to 2·82; and they were very fossiliferous, their surfaces revealing casts of goniatites. The following forms were found in these bullions:—*Pterinopecten papyraceus*, *Dimorphoceras Gilbertsoni*, *Glyptioceras diadema*, *Listracanthus Wardi*, and *Acanthodes Wardi*.

#### (4) The Florence Marine Bed below the Gin Mine.

This horizon was discovered in driving a ‘crut’ at the Florence Colliery (19 in Pl. XXXIV) in 1903, and its position is shown in the following section:—

	Thickness in feet inches.	
GIN MINE .....	2	4
Clay-shales and rock .....	15	6
Shale, with thin layers of rock ...	37	10
Black bass .....	6	11
Grey shale .....	6	6 (Marine bed.)
COAL .....	0	10

About three years ago, I saw a specimen of the above-mentioned grey shale, crowded with *Lingula*, which had been found in the Ash Pit, Slippery Lane, Hanley (11 in Pl. XXXIV); but, at that time, its exact horizon could not be located. Owing to the imperfect light afforded by safety-lamps, the search underground for these marine horizons is very difficult, as there is actually no difference in colour, hardness, texture, jointing, bedding, or fracture, between them

<sup>1</sup> E. T. Newton, Quart. Journ. Geol. Soc. vol. lx (1904) pp. 1–8 & pl. i.

and the non-marine shales of the Coal-Measures, to assist the worker. After long and fruitless search at many collieries, I was delighted when a student brought to me a specimen from the Florence Colliery, which at once allowed of the horizon being located and examined *in situ*. It is probable that this horizon is the lower marine bed discovered by Amison in 1865, to which reference has already been made (p. 500).

At the Florence Colliery the upper portion of this deposit was crowded with *Lingula mytiloides*, scattered throughout the shale, and not confined to one 'parting' or bedding-plane. The individuals were unusually large and well developed, and no other forms were associated with them.

The following list has been obtained from this bed:—

[c. = common ; v.a. = very abundant.]	SLIPPERY LANE. No. 11 (Pl. XXXIV).	FLORENCE COLLIERY. No. 19 (Pl. XXXIV).	SPEED- WELL?	
<i>Lingula mytiloides</i> , Sow.....	*	*	.....	v.a.
<i>Ctenodonta levirostris</i> , Portl. ...	.....	*	*	
<i>Edmondia</i> sp. ....	.....	*		
<i>Nucula</i> .....	.....	.....	*	
<i>Pterinopecten papyraceus</i> (Sow.) .....	.....	*	.....	c.
<i>Pleuironautilus</i> sp. ....	.....	*	*	
<i>Goniatites</i> .....	.....	*	*	
<i>Beyrichia arcuata</i> , Bean .....	.....	*		

### (5) The Marine Bed above the Moss Coal.

This bed was discovered in 1894 by Mr. John Ward, during the sinking at Longton-Hall Colliery (18 in Pl. XXXIV). The position of the horizon with respect to the Moss Coal was ascertained by Mr. G. A. Mitcheson, F.G.S., to whom I am indebted for the following section:—

	Thickness in feet inches.		
Sandstone.....	8	10	
Black bass.....	16	6	(Marine bed.)
Fireclay and strong shales .....	5	0	{ <i>Carbonicola turgida</i> & <i>C. acuta</i> .
Black bass.....	2	0	
Lean ironstone-band .....	0	6	
Soft shale .....	0	2	
COAL .....	1	2	
Soft fireclay, with bands of stone.	4	0	
Sandstone .....	27	0	
Black bass .....	15	0	
Sandstone .....	8	6	
Shales .....	6	0	
Black and grey shales .....	33	0	
Moss COAL .....	4	3	('Sinkers' thickness.)

The only form discovered in the marine 'black bass' was *Lingula mytiloides*, Sow., but it occurred in numbers so large as to stamp

the character of the deposit as unmistakably marine. It was evenly distributed throughout the shale, and the individuals were fully developed and in a fine state of preservation.

### (6) Roof of the Single Two-Foot Coal or Moss Cannel.

This horizon was discovered by me in June 1901, during the sinking at Sneyd Colliery, Burslem (10 in Pl. XXXIV), and since then it has been widely traced in the Coalfield. Its position is shown in the following sections:—

#### (a) Sneyd Colliery, Burslem (No. 10, Pl. XXXIV).

<i>Thickness in feet inches.</i>		
Moss COAL .....	4	10
Shales .....	20	3
Dark shale .....	0	2 <i>Myalina compressa.</i>
Shales .....	10	0
Black shale .....	1	1
CANNEL COAL .....	{ 0	2 } <i>Lingula mytiloides.</i>
	{ 1	8
COAL .....	2	0

#### (b) Berry-Hill Colliery (No. 12, Pl. XXXIV).

<i>Thickness in feet inches.</i>		
Moss COAL.		
Measures .....	18	0
Dark shale .....	3	0
COAL .....	2	0

#### (c) Florence Colliery (No. 19, Pl. XXXIV).

<i>Thickness in feet inches.</i>		
Moss COAL .....	5	6
Dark shales, with thin bands of ironstone .....	} 9	9
Dark shale .....		
COAL .....	2	5 <i>Lingula mytiloides</i> [throughout.]

At No. 16 Pit, Silverdale (1 in Pl. XXXIV), this horizon was found immediately overlying the Single Two-Foot Coal (which in this locality is about 24 feet below the Single Four-Foot Coal). The significance of this discovery lies in the fact, that it has enabled us to identify with certainty the Single Four-Foot Coal of the west side of the anticlinal axis with the Moss Coal of the Potteries area.

The thinning-out of the measures between the Moss Coal and the Moss Cannel from 31 feet 6 inches at Sneyd (10 in Pl. XXXIV) to 15 feet 9 inches at Florence Colliery (19 in Pl. XXXIV)—that is, 50 per cent. in a distance of about  $5\frac{1}{2}$  miles—is worthy of remark.

The list from this horizon is confined to the following:—

[v.a.=very abundant.]	SNEYD COLLIERY. No. 10	BERRY HILL. No. 12	FLORENCE COLLIERY. No. 19	SILVER- DALE. No. 1	Pl. XXXIV.
<i>Lingula mytiloides</i> , Sow. ....	*	*	*	*	v.a.
<i>Myalina compressa</i> , Hind .....	*	*	*	*	v.a.

With respect to these forms, they were found quite distinct and separate from each other. The *Lingulae* were distributed through the shale and, what was rather remarkable, were also found in the upper portion of the Cannel Coal itself at Sneyd and at Silverdale. They are very numerous, but diminutive and dwarfed, and in this feature contrast markedly with those found in the marine bed overlying the Moss Coal (see p. 505). The *Myalinae* were, in every instance, confined to a very thin layer of the shale.

#### (7) Marine Bed over the Seven-Foot Banbury Coal.

In 1900 Mr. Wilmot Scrivens brought some fossiliferous ‘bullions’ to me, for the purpose of having the fossils named. It was then discovered that they were from a hitherto-unknown marine bed; and, as the underlying coal-seam was widely worked in North Staffordshire, efforts were at once made to trace the bed, with the result that it has been found *in situ* at Leycett (2 in Pl. XXXIV), Hayes Wood (No. 3), Minnie Pit, Halmerend (No. 4), Talk o’ th’ Hill (No. 5), Birchenwood (No. 6), Sneyd (No. 10), and Norton Collieries (No. 8); that is, right across the Coalfield from west to east.

The following sections show the relation of this horizon to the Seven-Foot Banbury Coal:—

##### (a) Birchenwood Colliery (No. 6, Pl. XXXIV).

Thickness in feet inches.

Dark-grey shale, with few bullions	5	0	(Marine horizon.)
Hard, compact black shale .....	3	0	<i>Beyrichia arcuata</i> .
Dark shale .....	1	10	<i>Carbonicola acuta</i> .
FOURTH RIDER COAL.			
Shales .....	3	7	
THIRD RIDER COAL.			
Shales .....	6	6	
SECOND RIDER COAL.			
Shales .....	15	0	
FIRST RIDER COAL.			
Shales .....	100	0	
SEVEN-FOOT BANBURY COAL.			

## (b) Sneyd Colliery (No. 10, Pl. XXXIV).

<i>Thickness in feet inches.</i>		
Dark-grey shale .....		(Marine bed.)
RIDER COAL .....	0	4
Shales .....	23	9
RIDER COAL .....	2	2
Dirt-band.....	0	5
COAL .....	0	2
Shales and rock-binds.....	34	2
RIDER COAL .....	3	2
Shales, with thin bands of sand- stone.....	59	6
SEVEN-FEET BANBURY COAL.		

## (c) Norton Colliery (No. 8, Pl. XXXIV).

<i>Thickness in feet inches.</i>		
Dark-grey shales with nodules ...	21	0
COAL.....	0	8
Shales and rock-binds .....	19	9
COAL.....	2	3
Shales and rock-binds .....	15	9
COAL.....	2	0
Compact argillaceous rock .....	108	0
SEVEN-FEET BANBURY COAL.		

The upper 6 feet of  
these shales contain  
the marine fossils.

## (d) Leycett Colliery (No. 2, Pl. XXXIV).

<i>Thickness in feet inches.</i>		
Shales, with large bullions.....	7	0
Dark shales .....	8	0
THIRD RIDER COAL .....	0	9
Shale.....	6	6
SECOND RIDER COAL .....	1	0
Shale.....	1	0
FIRST RIDER COAL .....	2	0
Shale.....	10	0
SEVEN-FEET BANBURY COAL .....	5	6
Fireclay.		

(Marine horizon.)

*Beyrichia arcuata* in  
the upper layers.

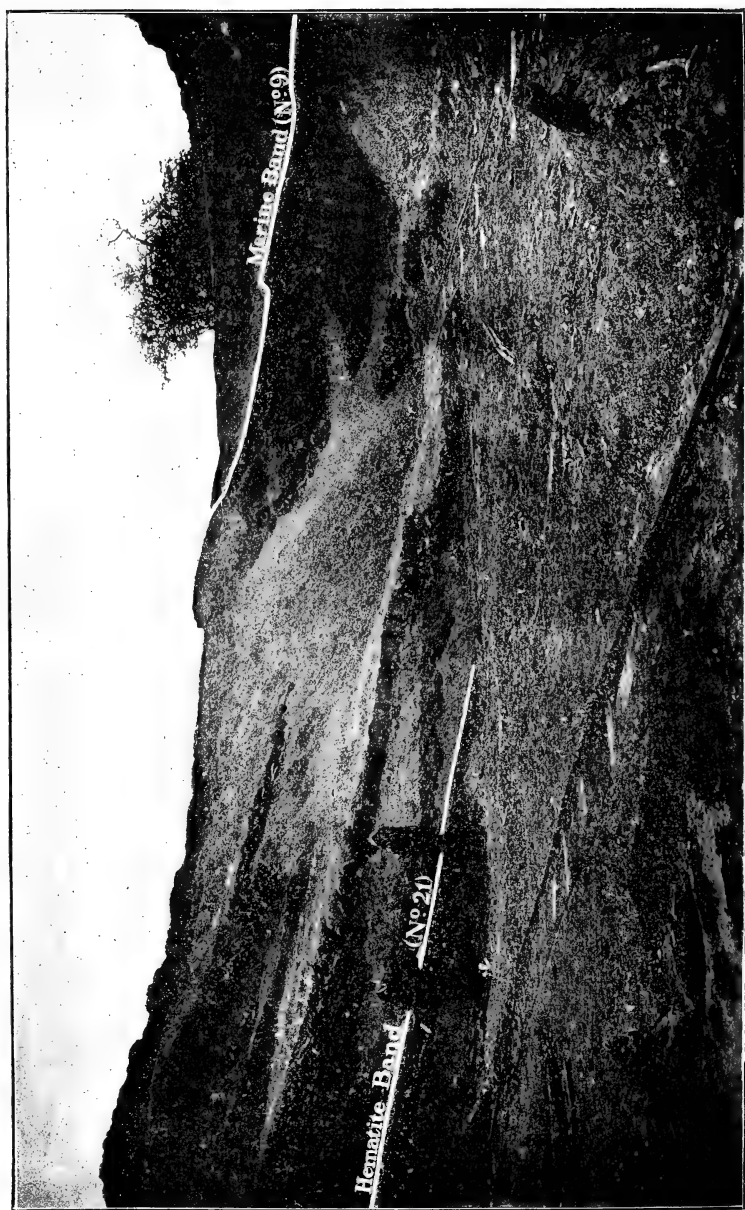
At Hayes-Wood Pit (3 in Pl. XXXIV) the marine horizon is only about 15 feet above the Seven-Foot Banbury Coal.

On the west side of the Coalfield the fossiliferous 'bullions' are bigger, more abundant, and more geometrically shaped than on the east side; the specific gravity of these bullions ranges from 2.67 to 2.75.

The foregoing sections show abnormal thickening of the measures between the Seven-Foot Banbury Coal and the marine bed in the northern and eastern portion of the Pottery Coalfield.

Again, nothing is more remarkable than the erratic changes in the nature of the roof of this coal, which is 'rock' or fine sandstone at one place, and a soft laminated shale at another. A comparison

Fig. 2.—*Exposure of Coal-Measures at Weston Sprink, near Longton. (See pp. 509, 510.)*





of the sections at Norton (8 in Pl. XXXIV) and Sneyd (10 in Pl. XXXIV), which are only  $1\frac{1}{4}$  miles apart, illustrates the rapid alteration in character of a coal-seam, which is so much relied upon by practical mining-engineers for purposes of identification.

The following list has been obtained from this horizon :—

[a. = abundant.]	LEYCETT COLLIERY.	HAYES-WOOD COLLIERY.	MINNIE PIT, HALMEREND.	TALK O' TH' HILL.	BIRCHENWOOD No. 18 Pit.	SNEYD COLLIERY.	NORTON COLLIERY.	Pl. XXXIV.
	No. 2	No. 3	No. 4	No. 5	No. 6	No. 10	No. 8	
<i>Myalina compressa</i> , Hind .....	...	...	...	*	*			
<i>Pterinopecten papyraceus</i> (Sow.) .....	*	*	*	*	*	*	*	a.
<i>Posidoniella lævis</i> (Brown) .....	*	*						
<i>Lingula mytiloides</i> , Sow. ....	...	*	...	...	*	*	*	
<i>Glyphioceras</i> (?) <i>paucilobum</i> (Phill.) .....	*	*	*	...	*	*	*	a.
<i>Orthoceras</i> sp. ....	...	...	...	...	*	*	*	
<i>Pleuromutilus</i> sp. ....	...	...	...	...	...	...	*	
<i>Rhizodopsis sauroides</i> , Will. ....	*	...	...	...	*	...	*	
<i>Beyrichia arcuata</i> , Bean .....	...	...	...	...	*	...	*	
<i>Dithyrocaris testudineum</i> (?) ..	*	*	...	...	*			
Plant-remains (fragmentary) ...	...	*	...	...	*	*	*	

At Norton, Sneyd, and Birchenwood Collieries the uppermost layer of the marine shale contains *Lingula mytiloides*, unmixed with any other form.

*Pterinopecten* and *Glyphioceras* occur together, both in the bullions and in the shales; *Dithyrocaris* has only been found in bullions.

### (8) The Weston-Sprink Bed.

This marine horizon was discovered in 1899, by Mr. John Ward, in a marl-pit at Weston Sprink, near Longton (No. 13, Pl. XXXIV). Its exact position is lat.  $52^{\circ} 59' 9''$  N., long.  $2^{\circ} 6' 15''$  W. Fig. 2 (p. 508) is a reproduction of a photograph of the measures exposed at Weston Sprink, of which the following is the section, in descending order :—

	Thickness in feet inches.	
1. Surface-soil.		
2. Grey marl .....	2	6
3. Grit .....	0	6
4. Unlaminated red marl .....	2	4
5. Grit .....	2	0
6. Purple marls, with large lenticular patches of grit.	9	4
7. Thin hæmatite-bands .....	0	2
8. Grey and purple marls, with hæmatite-nodules.....	6	5
9. Dark-blue clay-shale (see fig. 2), marine band ...	0	2
10. SMUT-LAYER .....	0	$0\frac{1}{2}$
11. Dark fireclay .....	1	2
12. Purple marl, with large lenticular nodules of grit...	7	9
13. Grey marl .....	1	11

	Thickness in feet inches.	
14. Grit .....	1	0
15. Laminated purple and grey marl, with nodules.....	4	0
16. Grit (irregular) .....	1	0
17. Laminated purple and grey marl, with nodules ...	3	3
18. Thin hæmatite-band .....	0	2
19. Laminated purple marl, with gritty nodules .....	3	4
20. Grit .....	1	0
21. Hæmatite-band (see fig. 2, p. 508) .....	0	2
22. Purple and blue laminated marls, with nodules ...	2' 6" to 1' 10"	
23. Grit .....	1	0
24. Blue laminated marl.		

Unfortunately, the position of the foregoing strata in the Coal-Measures has not yet been ascertained.

#### NOTES ON THE WESTON-SPRINK SECTION.

- No. 4. Unlaminated red marl. Contains numerous remains of *Anthracomya minima* (Ludw.), which are much compressed; also reed-like plants.
- No. 7. Thin hæmatite-band. Contains *Scaldia minuta*, Hind, in abundance.
- No. 17. Purple and grey marls. Contain *Naiadites modiolaris* (Sow.) in great numbers; also *Acanthodes Wardi*, Egert., *Cœlacanthus elegans*, Newb., *Carbonia* sp., *Calamites Suckowii*, Brongn., *Lepidodendron* sp., and *Lepidostrobus* sp.
- No. 18. Hæmatite-band. Contains *Platysomus Forsteri* (H. & Atthey), *Rhizodopsis sauroides*, Will., *Beyrichia arcuata*, Bean, and *Lepidodendron* sp.
- No. 19. Laminated purple marls. Contain *Naiadites modiolaris* (Sow.), and *Lepidodendron* sp.
- No. 21. Hæmatite-band. Contains *Scaldia minuta*, Hind, and *Beyrichia arcuata*, Bean. (See fig. 2, p. 508.)
- No. 22. Purple and blue marls. About the middle of this deposit, above a 4-inch nodular calcareous band, occurs a single layer crowded with fragmentary fish-remains. Mr. John Ward has identified the following from this stratum, as well as those previously mentioned from this quarry, namely:—*Acanthodes Wardi*, Egert., *Cœlacanthus elegans*, Newb., *Ctenopterygius apicalis*, Ag., *Diplodus gibbosus*, Ag., *Helodus simplex*, Ag., *Megalichthys Hibberti*, Ag., *M. pygmæus*, Traq., *M. rugosus*, Young, *Pleuroplax Rankinei*, Ag., and *Rhizodopsis sauroides* (Will.).
- No. 9. The marine band (see fig. 2, p. 508) has yielded the following fauna:—

*Lingula mytiloides*, Sow.  
*Orbiculoides nitida* (Phill.).  
*Myalina compressa*, Hind.  
*Pterinopecten papyraceus* (Sow.),  
 common.  
*Pleuronauutilus* sp.  
*Acanthodes Wardi*, Egert.

*Cœlacanthus elegans*, Newb.  
*Diplodus gibbosus*, Ag.  
*Elonichthys monensis*, Egert.  
*Megalichthys Hibberti*, Ag.  
*Megalichthys rugosus*, Young.  
*Platysomus Forsteri*, H. & Atth.  
*Rhizodopsis sauroides* (Will.).

#### (9) Marine Horizon in the Cheadle Coalfield.

¶ On March 16th, 1903, in examining some cores from a borehole put down near the Old Brass-Works at Cheadle, I discovered this horizon. I again found the same bed on February 25th, 1904, during the sinking of a shaft at Draycott Colliery, and by its aid was enabled to predicate exactly the position of the Dilhorne or Six-Foot Coal at that locality. On November 21st, 1904, the bed was again sunk through, in a second shaft, at Draycott. The fossils

occur in a finely-laminated black shale, which constitutes the roof of a thin coal previously unknown, and situated between the Four-Feet Coal and the Dilhorne Coal of the Cheadle Coalfield. At Draycott Colliery the coal with the marine roof-shale is 71 feet 2 inches below the Four-Feet Coal, and the section of the marine band is as follows:—

<i>Thickness in feet inches.</i>			
Dark-grey shale.....	4	0	Plant-remains; <i>Lingula mytiloides</i> .
Black, fissile shale.....	7	10	(Marine bed.)
COAL .....	1	3	

A large amount of material, which proved to be highly fossiliferous, has thus been examined from the sinkings of these shafts, and in this work Mr. John Ward has co-operated with me. The fossils as a rule were most beautifully preserved, and the following list was obtained:—

[c.=common; f.c.=fairly common; r.=rare; n.r.=not rare; v.a.=very abundant.]	DRAYCOTT COLLIERY.	BOREHOLE.	
<i>Lingula mytiloides</i> , Sow. ....	*	*	in one layer.
<i>Productus scabriculus</i> (?) Mart. ....	*		
<i>Leiopteria longirostris</i> , Hind .....	*	...	r.
<i>Myalina compressa</i> , Hind .....	*	...	f.c.
<i>Posidoniella laevis</i> (Brown) .....	*	...	n.r.
<i>Posidoniella sulcata</i> , sp. nov. ....	*		
<i>Pterinopecten carbonarius</i> , sp. nov. ...	*		[v.a.
<i>Pterinopecten papyraceus</i> (Sow.) .....	*	*	very large &
<i>Dimorphoceras Gilbertsoni</i> (Phill.) ...	*	*	v.a.
<i>Orthoceras</i> .....	*	...	c.
<i>Pleuromacritus pulcher</i> , Crick.....	*	...	n.r.
<i>Temnocheilus carbonarius</i> , Foord .....	*		
<i>Bellerophon</i> .....	*	...	r.
<i>Acanthodes Wardi</i> , Egert. ....	*		
<i>Acrolepis Hopkinsi</i> , M'Coy .....	*		
<i>Cœlacanthus elegans</i> , Newb. ....	*		
<i>Lepidodendron</i> .....	*		
<i>Calamites</i> .....	*		
Reed-like plant .....	*		

The association of plant-remains with the marine mollusca is worthy of remark, especially as none of the mollusca which are regarded as of freshwater origin were found intermingled with them. This is the more noteworthy, as in the Borehole a bed containing *Carbonicola acuta* and *C. aquilina*, with *Spirorbis* attached, occurs about 15 inches above the marine forms; and, in working the shales from the sinking, special care was taken to ascertain whether, in this favourable juxtaposition of freshwater and marine forms, any intermingling takes place. The result was, in this instance, a decided negative.

Again, it is interesting to note the occurrence of *Lingula mytiloides*, which was a much-dwarfed form, in the uppermost layer of the

band, scattered through the shale, unaccompanied by any other organisms but fragments of plant-remains. This horizon marks the uppermost limit of the genus *Leiopteria* and the occurrence of a new form of *Pterinopecten*.

### Marine Beds near the base of the 'true Coal-Measures.'

For the purpose of completing the record of the marine bands at present known in the Coal-Measures of North Staffordshire, the following horizons below the Winpenny Coal may be noticed:—

#### (10) The Knypersley Marine Band.

This bed is mentioned by Warrington Smyth<sup>1</sup> as being exposed on the eastern side of the reservoir at Knypersley, and containing in abundance *Pterinopecten papyraceus*. Its horizon is given as being between the Winpenny Coal and the Four-Foot Coal.

#### (11) Horizons near the Crabtree, Stinking, or Four-Foot Coal.

There are three distinct and separate horizons of marine character in connection with this coal-seam.

The uppermost is recorded by William Molyneux<sup>2</sup> as occurring 50 feet above the Stinking Coal of the Churnet Valley, in the form of a thin band of lean ironstone containing remarkably-fine examples of *Pterinopecten papyraceus*.

The middle horizon comprises the roof-shale immediately overlying the Stinking Coal itself, and it was used, many years ago, for the purpose of correlating the Crabtree, the Stinking, and the Four-Foot Coals. The following list has been recorded from this band:—

	GOLDSITCH.	WETLEY MOOR.	CHURNET VALLEY.
<i>Langula mytiloides</i> , Sow. ....	...	*	*
<i>Posidoniella lavis</i> (Brown) ....	*	...	*
<i>Pterinopecten papyraceus</i> (Sow.) ....	*	...	*
<i>Schizodus antiquus</i> , Hind ....	...	*	
<i>Gastrioceras Listeri</i> (Mart.) ....	*	...	*
<i>Goniatites</i> .....	...	*	*
<i>Orthoceras</i> .....	*	...	*

The lowest horizon is recorded by Molyneux (*loc. cit.*) as occurring in a nodular ironstone, found below the Froghall hæmatite-deposit, and containing *Posidoniella* and *Goniatites*.

<sup>1</sup> 'The Iron-Ores of Great Britain' pt. iv, Mem. Geol. Surv. 1862, p. 264.

<sup>2</sup> Rep. Brit. Assoc. 1864 (Bath) p. 343.

## Doubtful Marine Horizons in the Pottery Coalfield.

In addition to the foregoing list of marine horizons, two others have been recorded from the Pottery Coalfield, the existence of which is extremely doubtful. They are:—

1. A few feet above the Gin Mine or Golden Twist.
2. About the Ten-Foot Coal.

(1) The horizon above the Gin Mine was recorded by William Molyneux,<sup>1</sup> and by Mr. John Ward in his valuable monograph of the North-Staffordshire Coalfields,<sup>2</sup> and from the latter it has spread over a large circle of publications. In an earlier paper, written nearer the time of the discovery of the band, Mr. Ward describes a similar horizon lying 'a short distance below the Gin Mine.'<sup>3</sup> This position agrees with the marine band described hereinbefore (pp. 500-503). After careful discussion with Mr. Ward, I gather that he is inclined to think that the word 'above' should have been printed 'below.' At any rate, I have watched sinkings and 'crut'-driving without finding any trace of a marine bed above the Gin Mine in the position described, which I therefore consider erroneous.

(2) The marine horizon about the Ten-Foot Coal is cited by Prof. Hull, in his 'Coalfields of Great Britain' 3rd ed. (1873) p. 178, and in a paper read before this Society, Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 628. I have taken every opportunity of verifying the position of this band, but without success; and I conclude that the specimens were probably collected from the spoil-heap of 'Lord Granville's colliery at Hanley,' and that the horizon was not examined *in situ*. This view is supported by an examination of the fossil-list from the horizon, which embodies a mixture of freshwater and marine mollusca; and such a commingling is contrary to my experience of the occurrence of these mollusca in all the other marine horizons with which I am acquainted. At the same time, such a mixture of forms is precisely what may be obtained from any colliery spoil-heap, which consists of the débris brought from all the levels that, for the time being, are in course of excavation. In this way, fossils from many horizons are tipped together. I consider, therefore, that the marine shells have come from some other horizon than that of the Ten-Foot Coal.

## IV. EXPLANATION OF THE MAP (PL. XXXIV).

The outline-map (facing p. 514) shows the railway and canal-system of North Staffordshire, with its chief towns. The position of the collieries where the marine horizons have been traced is also shown by numbered circles.

<sup>1</sup> Rep. Brit. Assoc. 1865 (Birmingham) p. 50.

<sup>2</sup> Trans. N. Staffs. Inst. Min. & Mech. Eng. vol. x (1890) p. 43.

<sup>3</sup> N. Staffs. Nat. F.-C.: Addresses, etc. 1875, p. 192.

It will be observed that, while these collieries lie all around the Coalfield, they are noticeably absent from the very heart of the district, the simple reason being that the more valuable coal-seams in the area exist at depths so great that no shafts have as yet been sunk to them.

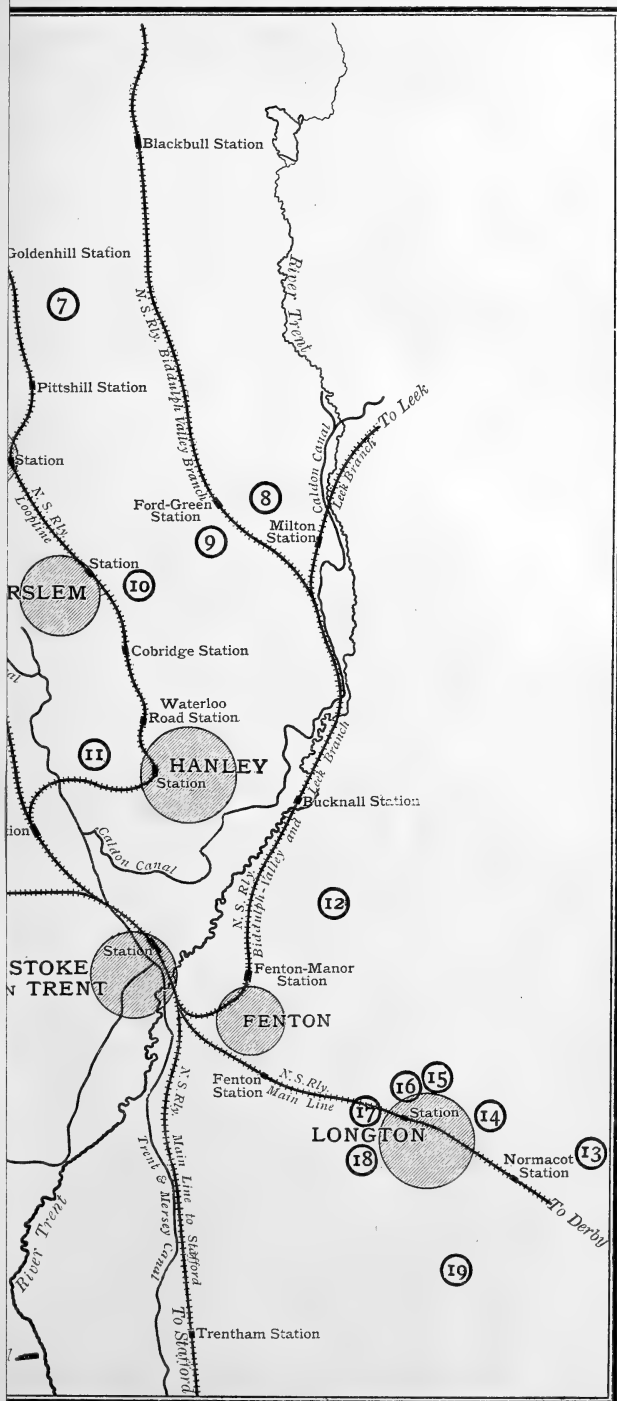
Another striking feature is the strong representation of collieries in the vicinity of Longton; this is largely due to the work of Mr. John Ward, and may be regarded as his 'mark' on the map.

#### V. DESCRIPTION OF THE DEPOSITS.

(a) Physical characters.—The marine bands, in every case, occur in shales, of various colour—sometimes dark, sometimes pale-grey. In the horizon below the Twist Coal at Nettlebank an impure limestone (2 feet 9 inches thick) was met with. As previously stated (p. 503), there is physically nothing to distinguish these marine shales from any other Coal-Measure shales. To test this point, I have repeatedly taken practical miners (who are exceedingly quick to notice slight differences in the rocks themselves) to examine spoil-heaps where a large amount of débris, containing a marine fauna, had been tipped. In every instance, they were unanimously of opinion that no points of difference were to be observed, save in the character of the contained fossils. The shales were more or less fissile, and in some cases were what miners call 'grewn' to the coal, that is, devoid of parting-plane: there was a total absence of anything of the nature of current-bedding, or any sensible break in the deposition of the measures contiguous to the marine horizons. Nodules and 'bullions' were found in two of the beds described, namely, the bed below the Twist Coal at Nettlebank and the Seven-Feet Banbury bed. Their abundance, however, varied considerably from place to place; and in the latter instance, on the west side of the Coalfield, they constitute quite a feature of the deposit, while on the east side they are comparatively rare. The bullions are invariably fossiliferous, and are especially worthy of the notice of collectors.

(b) Occurrence of the fossils.—The fossils are usually in a good state of preservation, and especially so in the bullions, where they are generally uncompressed; they were distributed throughout the shales, and not confined to any one layer or bedding-plane. In every band the individuals were numerous, and this in itself is a valuable feature for practical geologists, while for mining-engineers it is inestimable, since so much of their prospecting-work is done by drilling; and, where the core varies from 1 to 3 inches in diameter, if the fossils were at all rare, the bed would probably escape notice altogether. In this connection, it may be observed that the upper marine bed in the Cheadle Coalfield was first discovered in a 3-inch core.

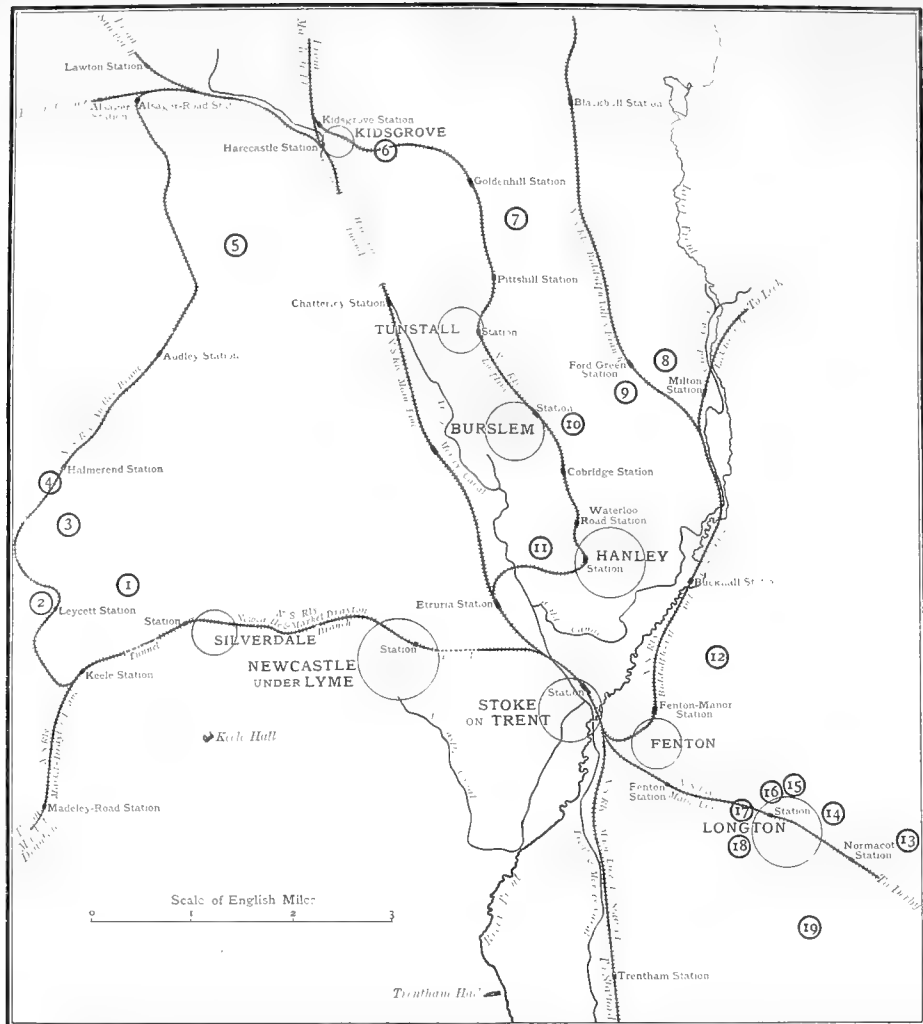
Respecting the fossils, with the exception of *Lingula mytiloides*, brachiopods are comparatively rare. The most abundant forms



SYSTEM OF NORTH STAFFORDSHIRE AND THE POSITION  
HAVE BEEN TRACED IN THE COAL-MEASURES.







OUTLINE-MAP SHOWING THE RAILWAY- AND CANAL-SYSTEM OF NORTH STAFFORDSHIRE AND THE POSITION OF THE COLLIERIES WHERE THE MARINE BANDS HAVE BEEN TRACED IN THE COAL-MEASURES.



obtained were *Pterinopecten papyraceus*, *Goniatites*, and *Lingula mytiloides*. The last-named species often occupies a distinct portion of the deposit—a peculiarity which has been previously noticed by William Molyneux<sup>1</sup> and Mr. John Ward.<sup>2</sup> In these layers, as a rule, it is not associated with any other genera (with the exception of *Orbiculoidea nitida*). In the following horizons, it is confined to the uppermost portion of the deposit, namely :—

The Florence Marine Bed.

The Seven-Foot Banbury Marine Bed.

The Upper Marine Band in the Cheadle Coalfield.

The fact that plant-remains are not rare in these horizons which are so strongly marine in character, has been mentioned previously.

Another observation has been emphasized by these researches, and that is the clear and distinct separation of the marine mollusca from those freshwater forms that are so common in the Coal-Measures, particularly in North Staffordshire. It is all the more necessary to lay stress upon this fact, because statements to the contrary are made by such authorities as Jukes and J. W. Salter respecting South Staffordshire<sup>3</sup>; and Prof. Hull, respecting the North-Staffordshire and other Coalfields.<sup>4</sup> The question in doubt, however, is whether those workers examined the beds *in situ*, or simply collected from the spoil-heaps of mines. In my opinion, there is no more fruitful source of error than the latter method, unless the precaution be taken, there and then, of verifying the results by observation of the beds in place. This distinct separation of the freshwater and marine faunas is corroborated by such careful workers as Phillips in Yorkshire,<sup>5</sup> Kirkby in Durham,<sup>6</sup> Molyneux<sup>7</sup> and Mr. John Ward<sup>8</sup> in North Staffordshire, and Mr. George Wild in Lancashire.<sup>9</sup> In North Staffordshire two interesting examples of the close proximity, but definite separation of these faunas, have been noted, namely:—The Moss-Cannel horizon and the Upper Marine Band in the Cheadle Coalfield. In the former instance, it requires very careful examination of the shales to be convinced of the distinctness of the layers containing *Myalina compressa* and *Carbonicola acuta*. When we consider the number of individuals of each class and the fact that they are usually scattered through the shale, it would not be surprising if an odd individual of either character should be found among a colony of the other class. The same peculiarity in the case of the Cheadle Upper Marine Band has already been mentioned (p. 511).

<sup>1</sup> Rep. Brit. Assoc. 1865 (Birmingham) p. 48.

<sup>2</sup> Trans. N. Staffs. Inst. Min. & Mech. Eng. vol. x (1890) p. 43.

<sup>3</sup> 'S. Staffs. Coalfield' 2nd ed. Mem. Geol. Surv. 1859, pp. 27, 58.

<sup>4</sup> Quart. Journ. Geol. Soc. vol. xxxiii (1877) pp. 628, 643.

<sup>5</sup> Encyclopædia Metropolitana, vol. vi (1845) art. Geology, p. 591.

<sup>6</sup> Quart. Journ. Geol. Soc. vol. xvi (1860) p. 414.

<sup>7</sup> Rep. Brit. Assoc. 1864 (Bath) p. 343.

<sup>8</sup> Trans. N. Staffs. Inst. Min. & Mech. Eng. vol. x (1890) p. 31.

<sup>9</sup> Proc. Yorks. Geol. Soc. vol. xiii (1895-99) p. 305.

The almost immediate succession, in order of deposition, of a coal-seam by a marine shale is a circumstance that may throw light on the conditions under which these seams were laid down. So far as attention has been directed to the nature of the coals overlain in this fashion, they do not differ in appearance or quality from the other coals of the district. The following seams are associated in this way with marine bands, namely:—

The Bay Coal.  
 The Priorsfield-Ironstone Coal.  
 The coal below the Gin Mine at Florence Colliery.  
 The Moss Cannel.  
 The Seven-Foot Banbury Rider Coal.  
 The coal below the Four-Foot at Draycott.  
 The Crabtree Coal.

#### VI. SCHEME OF SUBDIVISION OF THE COAL-MEASURES IN NORTH STAFFORDSHIRE BY MEANS OF MARINE BANDS.

Numerous attempts have been made in many of our coalfields to correlate the coal-seams in different localities; but, because palæontological evidence has been almost totally ignored in these efforts, to that extent the results may be regarded as guesses, more or less unsatisfactory. Such correlations lack anything of the nature of rigid proof. In North Staffordshire, the tracing of these marine horizons has placed the correlation on a different footing. This is attested by the fact that, in certain operations of mining, such as boring, sinking, and proving faults, these marine horizons have been of actual service when otherwise there would have been doubt.

In all Coal-Measure stratigraphy, however, it is advisable that the knowledge of marine bands should be supplemented by that of such other strata as satisfy the requirements of index-beds. In the district in question, several bands of thin limestone crowded with entomostraca have been traced; and the subdivision of the Coal-Measures, based on these palæontological 'lines' (which are not more than 450 feet apart in the series) simplifies the work of identification of certain seams.

In the following synopsis are enumerated, in descending order, the seams of coal and ironstone occurring between the index-beds mentioned above:—

##### *SPIROBIS*-LIMESTONE.

Bassey-Mine Ironstone and Coal.	
Little-Row or Gutter Coal.	
Peacock Coal.	Rich plant-bed.
Spencroft Coal.	
Gubbin Ironstone.	
Great-Row Coal.	
<i>SPIROBIS</i> -LIMESTONE	{ Lower limit of the range of <i>Anthracomya Phillipsi</i> .
Cannel-Row Coal.	
Wood-Mine Ironstone	Rich fish-bed.
Pennystone or Blackstone Ironstone.	
Deep-Mine Ironstone	Rich fish-bed.

Chalkey-Mine Ironstone.  
 New-Chalkey or New-Mine Ironstone.  
 Bungilow Coal.  
 Hanbury Ironstone-Measures.  
 Rag-Mine Ironstone.

## MARINE BAND.

Bay or Lady Coal.  
 Knowles or Winghay Coal.

## MARINE BAND.

Priorsfield Ironstone-Measures .....	Rich fish-bed.
Rusty-Mine Ironstone.	
Brown-Mine Ironstone .....	Rich fish-bed.
Gold-Mine Ironstone.	
Ash or Rowhurst Coal .....	Rich plant-bed.
Binghay or Bingey Coal.	
New-Mine Ironstone.	
Burnwood or Little-Mine Ironstone .....	<i>Anthracomya Adamsi.</i>
Pottery, Gin-Mine, or Twist Coal .....	Plant-bed.

## MARINE BANDS (Line A, in fig. 3, p. 518).

Bee Coal.  
 Doctor's Mine.  
 Birchenwood Coal.

## MARINE BAND.

Granville Coal.  
 Moss, Mossfield, Easling, or Single Four-Foot Coal.

## MARINE BAND.

Moss-Cannel or Single Two-Foot Coal.	
Single Five-Foot Coal .....	<i>Carbonicola subconstricta.</i>
Ragman Coal .....	Rich plant-bed.
Rough Seven-Foot Coal } Yard Coal.	
Hams Coal.	
Old Whitfield or Birches Coal.	
Ten-Foot Coal.	

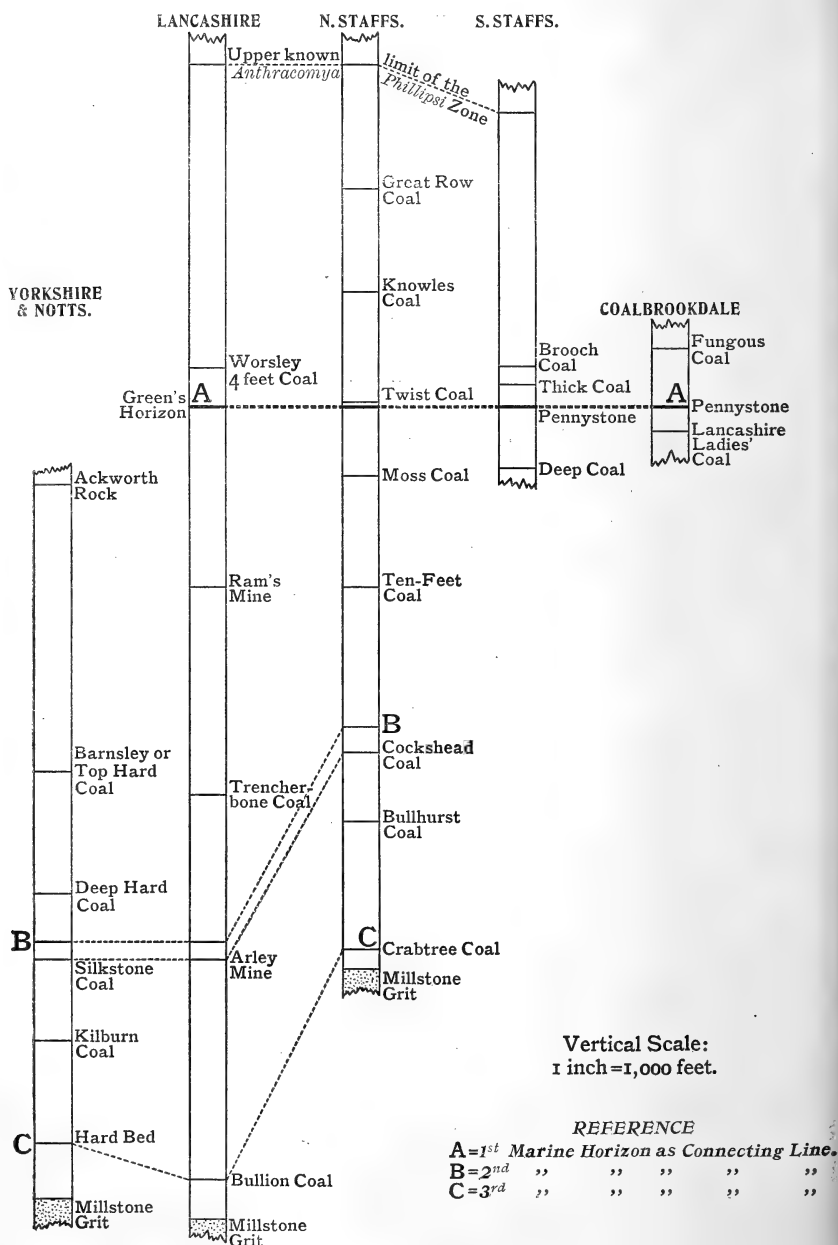
## SPIROBIS-LIMESTONE.

Bowling-Alley, Top Two-Row, Magpie, or Tatchinend Coal.	
.....	Rich plant-bed.
Holly-Lane or Two-Row Coal.	
Hard-Mine, Sparrow-Butts, Muck-Row, or Bowling-Alley Coal .....	{ <i>Anthracomya Williamsoni.</i> <i>Naiadites carinata.</i>
.....	Rich plant-bed.
Stinker's Coal.	

## MARINE BAND (Line B, in fig. 3, p. 518).

Little-Mine Ironstone and Coal.	
Seven-Foot Banbury, Seven-Foot Nabs, or Froggery Coal .....	{ <i>Carbonicola acuta,</i> <i>var. rhomboidalis.</i>
Cockshead, Eight-Foot Banbury, Eight-Foot Nabs, or Newport Coal.	<i>Carbonicola robusta.</i>
Whitehurst Coal.	
Bullhurst Coal.	
Winpenny Coal.	
Silver Mine.	
King Coal.	

Fig. 3.—Vertical sections illustrating the correlation of the Coal-Measures in Yorkshire, Lancashire, and the Midland Counties.



It should be mentioned that the highest and lowest horizons marked by *Spirorbis*-Limestones in the foregoing succession have been traced over practically the whole Coalfield, wherever they have not been removed by denudation.

## VII. CORRELATION OF VARIOUS COALFIELDS BY THE USE OF MARINE HORIZONS.

The existence of these definite horizons may be of service, not only for correlating the seams in any one coalfield, but they also offer the best means of correlating one coalfield with another. There can be little doubt that, at the time of their deposition, they formed absolutely the same plane-surface corresponding to sea-level, and in this respect they are of greater value than the freshwater molluscan zones of the Coal-Measures. With reference to the latter, we cannot overestimate the valuable work done by Dr. Wheelton Hind in establishing the order of succession of these mollusca; for, after scores of opportunities of testing their merits, their first failure in North Staffordshire has yet to be experienced. In comparison, however, the marine bands are more easily distinguished by practical mining-men, and they mark with greater precision a definite plane of deposit over wide areas of country. Their supreme adaptability, when present, for this purpose was recognized by earlier workers, who unfortunately assumed that marine bands were of rare occurrence, at any rate, in the most valuable portion of the Coal-Measures. The following instances, however, of attempts to correlate different Coalfields by these horizons may be enumerated, namely:—

(1) The *Pecten*, Hard, or Gannister Coal of Yorkshire was considered identical with the Bullion Coal of Lancashire by E. W. Binney,<sup>1</sup> and the latter was correlated with the Crabtree Coal of North Staffordshire by Warrington Smyth.<sup>2</sup> From the fauna and the position of these coals in the sequence, this identification may be considered as established (line C, fig. 3, p. 518).

(2) The Pennystone of South Staffordshire, in the opinion of J. W. Salter,<sup>3</sup> was the equivalent of the Pennystone of Coalbrookdale, because of the character of the marine mollusca found in connection with those deposits. It was adopted as a datum-line for the correlation of these coalfields by S. Bowkley<sup>4</sup> and Mr. Daniel Jones<sup>5</sup>; and this met with the approval of Sir Andrew Ramsay.<sup>6</sup>

(3) The Bay Coal and Priorsfield horizons of North Staffordshire were regarded as correlative of Green's marine bed at Ashton-under-Lyne by the late Robert Etheridge,<sup>7</sup> but with this view I

<sup>1</sup> Trans. Manch. Geol. Soc. vol. iv (1862-64) p. 18.

<sup>2</sup> 'The Iron-Ores of Great Britain' pt. iv, Mem. Geol. Surv. 1862, p. 264.

<sup>3</sup> 'The South Staffordshire Coalfield' 2nd ed. Mem. Geol. Surv. 1859, p. 27.

<sup>4</sup> Trans. S. Midland Inst. vol. ii, p. 65.

<sup>5</sup> Rep. Roy. Coal-Comm. vol. i (1871) pp. 121-22.

<sup>6</sup> 'The South Staffordshire Coalfield' 2nd ed. Mem. Geol. Surv. 1859, p. 58.

<sup>7</sup> 'Geology of the Country round Stockport, Macclesfield, &c.' Mem. Geol. Surv. 1866, p. 94.

cannot agree. The fauna contained by the last-named horizon was said by J. W. Salter to be 'comparable with that of the Lower Coal-Measures of Shropshire,<sup>1</sup> by which, I presume, was meant the Pennystone of Coalbrookdale. This identification, by the evidence of the fauna and the position of each horizon in the Coal-Measure Series, is, in my opinion, correct. The extraordinary fauna contained in these beds in Lancashire, Coalbrookdale, South Staffordshire, and in the Gin-Mine or Twist Coal of North Staffordshire, leaves little room for doubt that this horizon may be used as the first connecting-line extending between those coalfields (A, in fig. 3, p. 518).

The following analysis of the lists from all these districts, together with the stratigraphical position of the horizon in each coalfield, constitutes the justification of this conclusion :—

	NORTH STAFFS.	SOUTH STAFFS.	COALBROOK- DALE.	LANCA- SHIRE.
<i>Archæocidaris</i> .....	*	*		
<i>Lingula mytiloides</i> , Sow. ....	*	*?		
<i>Orbiculoidea nitida</i> (Phill.) ....	*	*	*	
<i>Productus scabriculus</i> , Sow. ....	*	...	*	
<i>Ctenodonta levirostris</i> , Portl. ....	*	...	...	*
<i>Nuculana acuta</i> , Sow. ....	*	...	*	*
<i>Pseudamusium fibrillosum</i> (Salt.) ...	*	...	...	*
<i>Pterinopecten papyraceus</i> (Sow.) ...	*	...	*	
<i>Ephippioceras costatum</i> , Foord ....	*	...	*	
<i>Orthoceras</i> aff. <i>asciculare</i> , Brown ...	*	...	*	
<i>Tennocheilus concavus</i> (Sow.) .....	*	...	*	
<i>Conularia quadrisulcata</i> , Sow. ....	...	*	*	
<i>Listracanthus</i> .....	*	...	...	*

The second line (B, fig. 3, p. 518) may be taken as the Seven-Feet Banbury marine bed in North Staffordshire. Mr. Walcot Gibson, of the Geological Survey, kindly showed me the marine bed discovered by him in Nottingham, and reported as lying about 80 feet below the Furnace Coal (or 76 feet above the Blackshale Coal) of that district.<sup>2</sup> On the occasion of that visit I expressed the opinion that the suite of fossils collected from the band corresponded most nearly with that of the Seven-Feet Banbury bed, and this view has been confirmed by subsequent work. In both coalfields this marine horizon is similarly situated with respect to the zone of *Carbonicola robusta* (a good zoning form), which in Nottinghamshire is found in connection with the Silkstone or Blackshale Coal, and in North Staffordshire occurs near the Cockshead Coal. It is most interesting to recall the fact that Henry Denny in 1845 recorded the existence of a marine band containing *Lingula*, 82 feet above the Silkstone Coal,<sup>3</sup> verifying in a remarkable way the identity of the Silkstone Coal of the Barnsley area with the

<sup>1</sup> 'Geology of the Country around Oldham' Mem. Geol. Surv. 1864, p. 65.

<sup>2</sup> 'Summary of Progress of Geol. Surv. U. K. for 1902' 1903, p. 16.

<sup>3</sup> Proc. Yorks. Geol. & Polytechn. Soc. vol. ii (1842-48) p. 293.



Blackshale Coal of Nottingham. Prof. Hull, referring to the Silkstone Coal of Yorkshire, says that it is 'undoubtedly identical with the Arley Mine of Lancashire,'<sup>1</sup> but he adduces no evidence in support of this statement. We now know, however, that the Arley Mine of Lancashire is the *Carbonicola-robusta* Zone; and very recently Mr. John Gerrard announced the discovery of a marine band in its proximity at Victoria Colliery, Standish. Consequently, the identity of the horizon in the coalfields of Yorkshire and Nottinghamshire, Lancashire, and North Staffordshire rests upon the following facts:—(a) Its proximity to the zone of *Carbonicola robusta*; (b) its relation to one of the most noted coal-seams in each district; (c) its position near the base of the most valuable portion of the Coal-Measures; and (d) the nature of the fossils collected from the horizon in each coalfield.

The following list is common to the different coalfields:—

	NORTH STAFFS.	NOTTS.	LANCA- SHIRE.
<i>Lingula mytiloides</i> , Sow. ....	*	*	
<i>Myalina compressa</i> , Hind .....	*	*	
<i>Pterinopecten papyraceus</i> (Sow.) .....	*	*	*
<i>Orthoceras</i> sp. ....	*	*	*
<i>Goniatites</i> .....	*	*	*
Plant-remains .....	*	*	

The third line (C, in fig. 3, p. 518) is that suggested by Phillips, Binney, and Warrington Smyth, namely, the marine shales overlying the Hard Bed of Yorkshire, the Bullion Coal of Lancashire, and the Crabtree Coal of North Staffordshire. The fauna found at this horizon, common to these coalfields, is tabulated in the following list:—

	NORTH STAFFS.	YORK- SHIRE.	LANCA- SHIRE.
<i>Lingula mytiloides</i> , Sow. ....	*	...	*
<i>Posidoniella lævis</i> (Brown) .....	*	...	*
<i>Pterinopecten papyraceus</i> (Sow.) ...	*	*	*
<i>Gastrioceras Listeri</i> (Mart.) .....	*	*	*
<i>Goniatites</i> .....	*	*	*
<i>Orthoceras</i> .....	*	*	*

Its position in relation to the Millstone Grit is also confirmatory of the correctness of this identification.

The southward attenuation of the Coal-Measure Series in the great area connected during deposition, which is represented in

<sup>1</sup> 'The Coalfields of Great Britain' 3rd ed. (1873) p. 241.

section by fig. 3, has been frequently noted within narrow vertical limits, as in the case of the Warwickshire Coalfield from Tamworth to Bedworth, and of South Staffordshire from Cannock Chase to Dudley—indeed, this is shown quite diagrammatically in the Thick Coal itself, while the evidence for it in North Staffordshire has been referred to in this paper (p. 505). The remarkable persistence of seams of coal in comparison with the general thinning-out of the Coal-Measures is worthy of special attention. This collective decrease in thickness is clearly shown in fig. 3 (p. 518), which indicates that the strata between the lines A and B have been most affected by this process.

### VIII. CONCLUSION.

These marine beds, which have been described at length in the foregoing pages, are seen to be true zoological zones, indicative of special conditions of deposit: they are persistent, and their contained fossils are abundant and easily recognized.

Recent work has shown that they are more numerous in the Coal-Measures than has been hitherto suspected. They are generally to be met with in shaft-sinkings, borings, and cross-measure drifts, if carefully looked for: in such circumstances, however, the discoverer should not rest satisfied until he has personally located the horizon *in situ*.

In accounting for the presence of these bands among strata of freshwater origin, it is not necessary to assume vertical oscillation of the ground, for they are sufficiently explained by the occasional recurrence of somewhat excessive subsidences during a general and prolonged movement of depression. Thus, inroads of the sea would be permitted over an extensive area, which we may consider was land-locked. This area embraced the sites of the coalfields of Lancashire, Yorkshire, Derbyshire and Nottinghamshire, Leicestershire, Warwickshire, North and South Staffordshire, and Shropshire, the measures in which were laid down as continuous deposits; for the existence of these marine beds renders untenable the theory that each coalfield was a 'separate area of deposition.'

Furthermore, these recurrences of marine conditions cannot be regarded as more characteristic of the lowest portion of the Coal-Measures, for the richest horizon of all is the Gin-Mine or Penny-stone Bed, which is high up in the 'true Coal-Measures.'

While the stratigraphy of nearly every formation has been based on palæontological data, it is to be regretted that (in this respect) the Coal-Measures have been comparatively neglected; but increased attention is now being given to the abundant material at our disposal.

In conclusion, I desire to express my indebtedness to Messrs. G. A. Mitcheson, F.G.S., and J. Lockett for allowing me to examine *in situ*, and to collect from, several marine horizons at collieries under their charge; to Mr. E. P. Turner for preparing

diagrams in illustration of this paper, and for assistance in carrying out these researches; and to the following students for similar help, namely: Messrs. W. Plant, W. G. Salt, and W. Scrivens.

The authoritative naming of the fossils was essential, and to this matter Dr. W. Hind and Mr. J. Ward have devoted much time and trouble: it is due to these two geologists to acknowledge the assistance derived from their pioneer-work in connection with the palæontology of the North Staffordshire Coalfield, which promises results equally valuable when applied to the other British coalfields. To the following experts my thanks are also tendered, for naming fossils mentioned in this paper, namely: Dr. F. A. Bather, Mr. G. C. Crick, Dr. A. H. Foord, Mr. R. Kidston, F.R.S., Mr. E. T. Newton, F.R.S., Dr. A. S. Woodward, F.R.S., & Dr. Henry Woodward, F.R.S.

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## X. NOTES on the PALÆONTOLOGY. By Dr. WHEELTON HIND.

## Introduction.

It has been known for some time that thin bands containing marine shells occur in several coalfields, and from time to time figures and descriptions have been published. Among the earliest of these publications were Sowerby's descriptions and figures of the marine mollusca from the Pennystone Ironstone of Coalbrookdale, in Prestwich's memoir.<sup>1</sup> Perhaps the other most important publication is that by Mr. George Wild, in which a large number of marine mollusca were figured.<sup>2</sup>

So well known was the occurrence of marine fossils, as distinct from the bands of *Carbonicola*, *Anthracomya*, and *Naiadites*, that Prof. Hull, in his paper on 'The Upper Limit of the Essentially-Marine Beds of the Carboniferous Group of the British Isles',<sup>3</sup> included the Gannister Series or Lower Coal-Measures with the Millstone Grits and the series of shales and black limestones below them, which he erroneously correlated with the Yoredale Series of Wensleydale.

This classification is obviously unsound; (1) because the Gannister Series is not wholly marine in origin, for it contains beds in which the marine fauna is absent; and (2) a marine fauna is not limited to the Gannister Series, but recurs at several horizons in the middle portion of the Coal-Measures, which are therefore not 'essentially freshwater or estuarine beds.' Indeed, there is an unbroken succession from the base of the Pendleside Series to the top of the Coal-Measures, at times marine, at times estuarine, or of freshwater origin. This thick series contains two distinct molluscan faunas, which recur with irregular alternations. One fauna is characterized by the *Unio*-like genera *Carbonicola* and *Anthracomya*, and the *Dreissensia*-like *Naiadites*; the other by *Pterinopecten papyraceus*, *Posidoniella*, with many species of Cephalopoda: and the two never mix.

<sup>1</sup> Trans. Geol. Soc. ser. 2, vol. v (1840) pp. 442-44, 490-93, & pls. xxxix-xli.

<sup>2</sup> Trans. Manch. Geol. Soc. vol. xxi (1891-92) pp. 364-400 & pls. i-iii.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xxxiii (1877) pp. 613-50.

It is important to note in the Coal-Measures certain species which are found in Carboniferous rocks of a much earlier age, especially in the case of lamellibranchs, gasteropods, and brachiopods. It is curious that, in the majority of these forms, changes in the organism due to evolution cannot be demonstrated, and therefore apparently the number of marine forms found, as yet, only in the Coal-Measures is small.

Of all the marine bands, that which occurs below the Gin-Mine Coal contains the richest fauna, alike in the number of genera, of species, and of individuals. Certain of the species which occurred here were new to science; others had not previously been described from British rocks; and the majority of species, if not identical, have a very close affinity to forms which are known at much lower horizons in the Carboniferous sequence.

### Palæontological Description.

#### Pisces.

The fish-fauna of the Marine Band associated with the Gin-Mine Coal is very peculiar, and has been the subject of two important papers. One by Dr. A. Smith Woodward, on *Listracanthus*,<sup>1</sup> the other by Mr. E. T. Newton on *Edestus*.<sup>2</sup>

The occurrence of *Listracanthus* had previously been noted by Mr. H. Bolton from the roof of the Bullion Mine, Lower Coal-Measures, and the Marine Band of the middle part of the Coal-Measures, in the River Tame, at Dukinfield.<sup>3</sup>

Species of *Listracanthus* have been found in the Culm-Measures of Herborn<sup>4</sup>; also in the Culm of Magdeburg, by Wolterstorff.<sup>5</sup> These beds I regard as the homotaxial equivalents of the Pendleside Series of the Midlands. *Listracanthus* has also been collected from beds, at Clavier, near Dinant (Belgium), which contain the typical fauna of the Pendleside Series. L. G. de Koninck has described a specimen, under the name *L. hystrix*, from Castiaux, near Mons, Assise vi<sup>6</sup>; and Dr. X. Stainier quotes the genus from Argenteau, near Liège.<sup>7</sup> Both of these localities are situated on beds below the horizon of the Lower Coal-Measures, and in both places *Listracanthus* is associated with a marine fauna. We may therefore consider that *Listracanthus* always had a marine habitat. Many of the fishes associated with it in the bed below the Gin Mine are also found with a non-marine fauna.

<sup>1</sup> Geol. Mag. 1903, p. 486.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. lx (1904) p. 1.

<sup>3</sup> Geol. Mag. 1896, p. 424.

<sup>4</sup> A. von Kœnen, Neues Jahrb. 1879, p. 341.

<sup>5</sup> 'Das Untercarbon von Magdeburg' p. 18.

<sup>6</sup> Ann. Mus. Roy. d'Hist. Nat. de Belg. vol. ii (1878) p. 75.

<sup>7</sup> 'Matériaux pour la Flore & la Faune du Houiller de Belgique' Ann. Soc. géol. de Belg. vol. xix (1892) p. 348.



The list of fossil fishes from the bed below the Gin Mine is as follows:—

*Acanthodes Wardi*, Edg.  
*Celacanthus elegans*, Newb.  
*Diplodus gibbosus*, Ag.  
*Edestus triserratus*, E. T. Newton.  
*Elionichthys Egertoni*, Ag.  
*Listracanthus Wardi*, A. S. Woodw.  
*Megalichthys Hibberti*, Ag.  
*Megalichthys intermedius*, A. S. Woodw.

*Megalichthys rugosus*, Young.  
*Orodus* sp. (?).  
*Platysomus parvulus*, Ag.  
*Platysomus Forsteri*, H. & Atth.  
*Pleuroplax Rankinei*, Ag.  
*Rhizodopsis sauroides* (Will.).  
*Sphenacanthus*? (teeth).

### Echinodermata.

*Archæocidaris* sp. (Pl. XXXV, figs. 1 & 1a) is represented in the marine band below the Gin Mine by numerous spines, teeth, and a few interambulacral plates. The radioles are very long and slender, with numerous, comparatively-large, opposite spinules, which project upwards and downwards. The plates have the general character of the genus. Some of the material has been submitted to Dr. F. A. Bather, F.G.S., who hesitates to refer the specimens to any particular species, as much uncertainty exists in regard to the type.

*Archæocidaris* has been previously noted from the British Coal-Measures. Jukes quotes, on the authority of Edward Forbes, 'an *Echinus* very much broken up, probably *Archæocidaris*,' in the lower part of the New-Mine Ironstone, Oldbury.<sup>1</sup>

### Brachiopoda.

The Brachiopoda are represented in the Coal-Measures by seven species, and the individuals are nearly always dwarfed.

*LINGULA MYTILOIDES*, Sow. (Pl. XXXV, fig. 2.)

This species is not uncommon at several horizons. As a rule, it occurs in a black shale by itself; in the case of the marine band below the Gin-Mine Coal, it is found immediately above the bed containing the other marine shells. The shell is usually much dwarfed, and the biggest specimen that I have seen measures only 8 millimetres in its greatest diameter.

Mr. John Ward mentions the occurrence of *Lingula squamiformis* from the North-Staffordshire Coalfield,<sup>2</sup> but I think that he was misled by crushed specimens. I have seen no specimens properly referable to this species in his collections.

Localities.—North Staffordshire: above the Bay Coal; in the roof of the Priorsfield Ironstone; below the Gin-Mine Coal (two beds); over the Moss Coal; above the Moss Cannel-Coal; marine band, Weston Sprink; above the Seven-Foot Banbury Coal; 71 feet below the Four-Foot Coal, Cheadle; above the Crabtree Coal.

Leicestershire Coalfield: at 453, 606, and 663 feet from the surface at Nailstone Colliery. Nottinghamshire Coalfield: 524 and

<sup>1</sup> 'Geology of the South Staffordshire Coalfield' Rec. of the School of Mines, vol. i, pt. ii (1853) p. 194.

<sup>2</sup> Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x (1890) p. 123.

258 feet above the Top-Hard Coal; 80 feet below the Furnace Coal. Durham Coalfield: 17 feet 4 inches above the Five-Quarter Coal. Lancashire Coalfield: 2070 feet below the surface at Bradford Colliery, above the Bullion Coal. Yorkshire Coalfield: above the Middleton-Mine and Silkstone Coals. Cannock-Chase Coalfield: Fair Oaks Colliery.

This species also occurs in the Pendleside Series of North Staffordshire.

ORBICULOIDEA NITIDA (Phillips). (Pl. XXXV, fig. 3.)

This species is much dwarfed, and rare in the marine band below the Gin-Mine Coal. Mr. John Ward figured a specimen (*op. supra cit.*) of this species from the Lower Coal-Measures of Cheadle (North Staffordshire). Above the Pennystone Ironstone, Coalbrookdale, it occurs very well-developed, but in this bed *Productus scabriculus* and *Spirifer bisulcatus* are also very fine.

Localities.—North-Staffordshire Coalfield: above the Bay Coal; above the Priorsfield Ironstone; below the Gin-Mine Coal, Nettlebank; marine band, Weston Sprink.

South Staffordshire: Pennystone. Coalbrookdale Coalfield: with the Pennystone and Chance Pennystone Ironstone. Nottinghamshire Coalfield: 524 feet above the Top-Hard Coal. Durham Coalfield: 148 fathoms below the Hutton seam.

This species also occurs in the Pendleside Series of the River Hodder (Yorkshire), and 500 feet below the Third Grit at Congleton Edge (Cheshire), and as low down as the Redesdale Ironstone, Northumberland.

CHONETES LAGUESSIANA, mutation  $\theta$ . (Pl. XXXV, fig. 4.)

A peculiar mutation of *Chonetes* occurs in the band below the Gin-Mine Coal. Its distinguishing characters are:—

1. The transverse form in the adult.
2. The extended hinge-line, and rolled ear-like projections (an adult character).
3. The comparatively-large area.
4. The intercalation of ribs.
5. The tendency to deep, irregular, concentric grooves in the adult.

This shell is fairly abundant at the horizon mentioned above, and I know this special mutation from the Coal-Measures of one of the Somerset Coalfields.<sup>1</sup> Jukes quotes a small *Chonetes* from the Pennystone Ironstone of South Staffordshire, on the authority of Edward Forbes. On comparison with the form of *Chonetes* which occurs 500 feet below the Millstone-Grit Series at Congleton Edge (Cheshire), the Millstone-Grit form is seen to have much finer ribbing and to be less transverse. I have noted the same elongate hinge-line and pointed extremities in specimens of *Chonetes* from the Lower Limestone Series of Beith (Ayrshire). The fact that in the young state the Coal-Measure form does not exhibit the peculiarities of its adult, indicates that these characters are the result of evolution.

<sup>1</sup> Mr. H. Bolton has discovered a rich marine bed at Ashton-Vale Colliery, near Bristol, 270 feet below Gay's-Vein Coal.

*PRODUCTUS SCABRICULUS* (Martin).

A crushed example of what I take to be this species is found in the marine band, 71 feet below the Four-Foot Coal of Cheadle. It is not surprising that this species should occur at this horizon, for it is common in the Pennystone Ironstone of Coalbrookdale, and is also known in the bed 500 feet below the Millstone Grit at Congleton Edge. Jukes reports this species, on the authority of Edward Forbes, from the Pennystone Series of South Staffordshire, and it also occurs 60 feet above the Thick Coal, at Hamstead Colliery.

*PRODUCTUS* sp. (Pl. XXXV, fig. 5.)

Several imperfect and immature examples of a *scabriculocostate Productus* have been obtained; these had been previously assigned to *Pr. semireticulatus*, a form which must be rigidly defined in the near future.

*PRODUCTUS ANTHRAX*, sp. nov. (Pl. XXXV, fig. 6.)

Dr. Arthur Vaughan, F.G.S., has kindly studied this form, and I append his remarks as follows:—

‘*Productus* β. (Gin Mine). (A pedicle-valve.)

- ‘ I. A descendant of the generic series of *Productus Cora* (Dav.), as shown by
  - (1) The short hinge-line (see the growth-lines on the brachial valve).
  - (2) The *Orthotetes*-like sculpture on the flanks.
  - (3) The emphasized wrinkles on the wings.
- ‘ II. Strong convergence towards *Productus hemisphericus* is indicated by
  - (1) The transversity and general convexity, but especially by the form and ornament of the beak and beak-region.
  - (2) The gradual and gentle slope of the medial area into the flanks.
- ‘ III. Homœomorphy with *Productus* aff. *burlingtonensis* (=my *Productus* cf. *Martini*) is distinctly suggested in the general aspect of the medial area.
  - (1) The medial line has an almost constant curvature.
  - (2) The medial area is flattened transversely, so as to be almost truly cylindrical.
 (The broad, very shallow sulcus and the few distant spines increase the resemblance.)
- ‘ IV. The *edelburgensis*-type of ribbing is very marked in this specimen, but is most probably (judging from other groups) merely a varietal character.’

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal.

*AMBOCCELIA CARBONARIA*, sp. nov. (Pl. XXXV, figs. 7 & 7 a.)

Specific characters.—Shell small, pedicle-valve elongate, tumid, with a broad, shallow, median furrow extending from the beaks. The beak is pointed and much curved. The brachial valve is much flatter, transverse, with a median, broad, shallow sulcus and a compressed zone near the front part of each lateral margin. The valves are almost smooth, the brachial showing distinct lines of growth.

Locality.—North Staffordshire Coalfield: below the Gin-Mine Coal, Nettlebank.

Observations.—I have referred this shell to a new species, because it differs widely from *Ambocœlia Urei*, being less transverse; and the median groove is much broader and less linear. *A. Urei* is known from the Limestone Series of Carlisle and a specimen has been figured from the marine band beneath the Farewell Rock at Glan Rhymney, in the South-Wales Coalfield.

### Gasteropoda.

*RAPHISTOMA RADIANS*, de Kon. 1881. (Pl. XXXV, figs. 8 & 8 a.)

*Euomphalus radians*, L. G. de Koninck, 'Descr. des Anim. Foss. Terr. Carb. de Belg.' 1843, p. 442 & pl. xxxiii bis, figs. 5 a-5 c.

*Raphistoma radians*, L. G. de Koninck, Ann. Mus. Roy. d'Hist. Nat. de Belg. vol. vi (1881) p. 135 & pl. xii, figs. 12-14.

This shell has not been previously described from British rocks. It does not attain to any great size, having a transverse diameter in the adult of 10 millimetres. The whorls number 6 or 7, and are much depressed and flattened. There is a large shallow umbilicus. The margin of the whorls is angular, and immediately below it is a very fine, shallow, spiral groove. The whorls are smooth above, but below (near the suture) there is a band of regular linear tubercles. The aperture of the shell is obliquely ovate. In Belgium, according to L. G. de Koninck, this species is not rare in the Calcareous Shale of Tournai; that is to say, it occurs in the lowest stage of the Carboniferous Limestone of that country. The same author also describes a somewhat bigger shell from the Viséan, under the name of *Raphistoma junior*, separating the two on account of the greater dimensions of the latter and the larger spiral angle. But the latter condition is a necessary corollary of larger growth, and I see no reason for the establishment of two species. The Rev. G. F. Whidborne<sup>1</sup> notes the occurrence of *R. junior* in the Pilton Beds; but, judging from the figures given by him, the ornament is more linear and not tuberculate, and I doubt whether his shell ought to be referred to L. G. de Koninck's species.

Localities.—The marine band below the Gin-Mine Coal, North-Staffordshire Coalfield; 500 feet below the Third Grit, Congleton Edge (Cheshire).

*TURBONELLINA FORMOSA*, de Kon., 1881. (Pl. XXXV, fig. 9.)

*Turbonellina formosa*, L. G. de Koninck, Ann. Mus. Roy. d'Hist. Nat. de Belg. vol. vi (1881) p. 79 & pl. ix, figs. 59-61.

Like the foregoing species, this shell has never been previously found in British rocks. If I am correct in referring it to de Koninck's species, it is rather larger than the unique example on which that species was established, which came from the Viséan

<sup>1</sup> 'Devonian Fauna of the South of England' (Monogr. Pal. Soc.) vol. iii, pt. i (1896) p. 54.

of Belgium. Some half-dozen specimens have been found in the marine band below the Gin-Mine Coal at Nettlebank, only one of them being well-preserved. The others, although retaining the spiral ornament, are much distorted by crushing. The shell may be recognized by its small (10 millimetres high), semiglobular form, consisting of five whorls, the last of which composes the greater part of the shell. The smaller whorls appear to be almost in the same plane. The aperture is nearly circular, and the surface is ornamented with several fine, spiral, linear ridges, which are separated by broader, concave, spiral spaces.

Locality.—North Staffordshire : below the Gin-Mine Coal.

*NATICOPSIS BREVISPIRA* (de Ryckholt) 1847. (Pl. XXXV, fig. 10.)

*Naticodon brevispira*, P. de Ryckholt, 'Mélanges paléontologiques' pt. i, 1847, p. 78 & pl. iii, figs. 8-9. (*Ex Acad. Roy. de Belg. Mém. couronnés, &c.* vol. xxiv.)

*Naticopsis brevispira*, L. G. de Koninck, Ann. Mus. Roy. d'Hist. Nat. de Belg. vol. vi (1881) p. 22 & pl. i, figs. 23-26.

I have obtained three small specimens of a shell, which I now refer to *Naticopsis brevispira* (P. de Ryckholt). They are much dwarfed, the biggest measuring only 7 millimetres in height and 8 mm. in breadth. Like the two preceding species, this one has not been previously recorded as occurring in British Carboniferous rocks. It is recognized by its short globose spire of about four whorls, the last occupying by far the major portion of the shell. The aperture is large and oval. There is no decided ornament, and the shell is almost smooth; but, under the microscope, fine lines and striæ of growth may be observed.

Locality.—North Staffordshire Coalfield: below the Gin-Mine Coal.

*LOXONEMA ACUTUM*, de Kon. 1881. (Pl. XXXV, fig. 11.)

*Loxonema acutum*, L. G. de Koninck, Ann. Mus. Roy. d'Hist. Nat. de Belg. vol. vi (1881) p. 46 & pl. iv, figs. 34-37.

It is often very difficult to determine species of this genus, owing to the fact that the shell generally adheres to the matrix, and I have been able to examine only a single example (Pl. XXXV, fig. 11) that has the test preserved. Other examples have occurred in the state of casts of the interior, or with the outer layer of shell removed. The peculiar marking is to be seen with the aid of a microscope, and consists of a number of incised curved lines on each whorl, better defined on the upper and more convex portions. Our shell measures only 10 millimetres in height, and its spire consists of about sixteen small convex whorls, the portion of the whorl which envelopes the preceding one having a moniliform ornament. Like the other gasteropoda, this species has not been previously recorded from British Carboniferous rocks.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal, Nettlebank.

**Lamellibranchiata.****SYNCYCLONEMA CARBONIFERUM, Hind. (Pl. XXXV, fig. 12.)**

This species was erected on a number of specimens from the marine band below the Gin Mine at Nettlebank (North Staffordshire). Figures and description were published in my Monograph of Brit. Carb. Lamell. vol. ii, pt. ii, p. 120 & pl. xix, figs. 3-6 (Pal. Soc. vol. lvii, 1903). Subsequently Mr. John Smith, of Kilwinning, sent me a shell from the Upper Coal-Measures of Dalziel (Lanarkshire), which he said was the only *Pecten* that he had ever seen in the Coal-Measures of the West of Scotland. This specimen proved to be *Synsyclonema carboniferum*, and is of importance as showing the wide horizontal distribution of the species. Probably others will be found in the Lancashire and Cumberland Coalfields, if a thorough search is carried out.

**PSEUDAMUSIUM FIBRILLOSUM (Salter). (Pl. XXXV, fig. 13.)**

This species is redescribed and figured in my Monograph (*op. supra cit.* p. 106 & pl. xvi, figs. 16-22). Specimens were obtained from the band below the Gin Mine at Nettlebank. It occurs also in the Coal-Measures of Ashton-under-Lyne, 450 feet above the Great-Mine Coal; in the Coal-Measures of Slieve Carna (Mayo); and at various localities in the Pendleside Series.

**PTERINOPECTEN PAPYRACEUS (Sow.). (Pl. XXXV, fig. 14.)**

This shell occurs at many horizons in the Coal-Measures and Pendleside Series. I regard it of importance as denoting a definite though thick zone, especially at the base, where its presence indicates a sudden change in the fauna. Although found in Scotland, in the Carboniferous Limestone Series of East Kilbride, it is, in Ireland and England, limited to the Pendleside Series, Millstone Grit, and Coal-Measures. It occurs in Co. Clare and Derbyshire in beds, which immediately succeed the Carboniferous Limestone with *Productus giganteus* and a Viséan fauna, indicating the sharp faunal change which takes place.

In the North-Staffordshire Coalfield it occurs: below the Gin-Mine Coal; above the Bay Coal-shale; Longton, the Florence marine bed; at Weston Sprink, the exact horizon being unknown; above the Seven-Foot Banbury Coal; and in the roof of the Two-Foot and Four-Foot Coals of Wetley Moor. In the Cheadle Coalfield it occurs 50 feet above and upon the Stinking, Coal, and 71 feet below the Four-Foot Coal; also above the Crabtree Coal of the Goldsitch basin.

In the Lancashire Coalfield it is abundant over the Bullion Mine, and is found over the Featheredge, the Gannister, and the Bullion Coals of Oldham. Yorkshire Coalfield: over the Hard-Bed Coal. Coalbrookdale Coalfield: over the Pennystone Ironstone.

**PTERINOPECTEN CARBONARIUS, Hind, 1904. (Pl. XXXV, fig. 15.)**

*Pterinopecten carbonarius*, Hind, 'Monogr. Brit. Carb. Lamellibr.' vol. ii pt. iii (1904) p. 128 & pl. xxv, figs. 14-16. (Pal. Soc. vol. lviii.)

I erected this species on shells obtained from the Cheadle Coal-

field and the Pendleside Series of Bosley Mine. It is important to distinguish it from *Pterinopecten papyraceus*, for which purpose the following characters may be relied upon:—

- (1) It is a much smaller shell; (2) its shape is quadrate-subcircular; and (3) the external ornament and arrangement of ribs.

Its ribs are broader and much less numerous, the anterior ribs being curved outwards near the lower margin; the ribs become obsolete over the postero-superior angle of the right valve, and the anterior ears have well-marked radiating ribs.

Localities.—North-Staffordshire Coalfield: marine band below the Gin-Mine Coal; 71 feet below the Four-Foot Coal, Cheadle. Black shales of the Pendleside Series, Bosley Mine (Cheshire); 270 feet below Gay's-Vein Coal, Bristol Coalfield.

*POSIDONIELLA SULCATA*, Hind, 1904. (Pl. XXXV, fig. 16.)

*Posidoniella sulcata*, Hind, 'Monogr. Brit. Carb. Lamellibr.' vol. ii, pt. iii (1904) p. 134 & pl. xxv, figs. 2-6. (Pal. Soc. vol. lviii.)

This shell attains a size of 25 by 35 millimetres, and it is very important to distinguish it from *Posidonomya Becheri*, which species indicates a zone at the base of the Pendleside Series. *Posidoniella sulcata* has the narrow hinge-line of its genus, and no anterior ear. Its ornament, consisting of concentric angular ridges, separated by wide, concave sulci, differs from the close, flattened, concentric ribs of *Posidonomya Becheri*.

I am of opinion that I saw, several years ago, a specimen of *Posidoniella sulcata* from the Lancashire Coal-Measures, in the cabinet of the late Mr. Neild, of Oldham, but all attempts to trace the specimen have failed. Mr. H. Bolton<sup>1</sup> quotes *Posidonomya lateralis*, a synonym of *P. Becheri*, as occurring in the Lower Coal-Measures of Lancashire. Possibly he may have mistaken a specimen of my species for it.

Localities.—This species was founded on numerous specimens from the marine band below the Gin-Mine Coal, North-Staffordshire Coalfield. It has also been found 71 feet below the Four-Foot Coal of Cheadle.

*POSIDONIELLA LÆVIS* (Brown). (Pl. XXXV, fig. 17.)

This species has its maximum in the Pendleside Series, and is not common in the Coal-Measures. I have not been able to observe any characters pointing to evolution in the later specimens. This may be due to the fact that, as it nearly always occurs in shales, the shell is so often crushed.

Localities.—North Staffordshire Coalfield: above the Stinking Coal, and with *Pterinopecten papyraceus* near Froghall Station, in the Cheadle district; 29 feet above the Seven-Foot Banbury; below the Gin-Mine Coal.

Lancashire Coalfield: above the Bullion Mine at Colne, Sholwer, Starring, and Dearnley; above the Gannister Coal, Pimbo, near Wigan; below the First Grit, Ipstones; 500 feet below the Third Grit, Congleton Edge.

<sup>1</sup> Trans. & Ann. Rep. Manch. Microsc. Soc. 1895.

*NUCULA GIBBOSA*, Fleming. (Pl. XXXV, fig. 18.)

This species has a very wide vertical range. It is found in the Calciferous Sandstone Series of Fife, and recurs at various localities, with an increasingly-higher horizon as the beds pass southward, until in the Midlands it ranges from the Pendleside Series to the Coal-Measures, and throughout this great thickness of strata appears unchanged in character. It is never found in pure limestone, but had always a muddy habitat. Specimens from the Coal-Measures are in no way dwarfed.

Localities.—Below the Gin-Mine Coal, North Staffordshire Coalfield; 300 feet below the Third Grit, Congleton Edge.

*NUCULA OBLONGA*, M'Coy. (Pl. XXXV, figs. 21 & 21 a.)

A single fragment of this somewhat rare species was obtained by the collector of the Geological Survey at Nettlebank (North Staffordshire). I was enabled to examine it, by the kind permission of Dr. F. L. Kitchin, F.G.S. Previously I had not known this species to occur above the shales which overlie the Little Limestone of the Yoredale Series.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal.

*NUCULANA SHARMANI*, R. Eth. fil. (Pl. XXXV, fig. 19.)

I have seen two examples of this species from the Coal-Measures, one of which shows the multidenticulate hinge, and the narrow escutcheon. This last character is important, as therein it differs from *Nuculana attenuata*, for which, from its shape, it might be mistaken. But *N. Sharmani* is more curved from before backwards. *Nuculana attenuata* occurs in the Coal-Measures of South Staffordshire, 60 feet above the Thick Coal at Hamstead.

Localities.—North-Staffordshire Coalfield: below the Gin-Mine Coal. In Scotland, *N. Sharmani* ranges from the Calciferous Sandstone Series to the Upper Limestone Series.

*NUCULANA ACUTA* (Sow.). (Pl. XXXV, fig. 20.)

This is a form which is, so far as known at present, confined to the Coal-Measures; it is much shorter and more acute than the other species of the genus.

Localities.—North-Staffordshire Coalfield: below the Gin-Mine Coal. Coalbrookdale Coalfield: above the Pennystone Ironstone.

*CTENODONTA LÆVIROSTRIS* (Portlock). (Pl. XXXV, fig. 23.)

This species is relatively more abundant than the other nuculiform shells. Practically, it has the same range as *Nucula gibbosa*, with which it is nearly always associated.

Localities.—North-Staffordshire Coalfield: below the Gin-Mine Coal. In the Pendleside Series, 500 feet below the Millstone Grit at Congleton Edge.



*CTENODONTA UNDULATA* (Phill.). (Pl. XXXV, figs. 22 & 22 a.)

In my monograph on the British Carboniferous Lamellibranchs I have figured the cast of a shell from the roof of the Gin Mine, Longton, as *Nucula undulata*. The genus should be more correctly *Ctenodonta*, and it would have been more correct to have given the horizon as below the Gin Mine.

This species is much more tumid and cylindrical than *Ctenodonta levirostris*. Several other examples occurred in the Nettlebank marine band, below the Gin Mine, on the same horizon as that in which the shell was first found at Longton.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal.

*SOLENOMYA PRIMÆVA*, Phillips. (Pl. XXXV, fig. 24.)

A single specimen was obtained by Mr. John Ward, many years ago, from below the Gin-Mine Coal at Longton; and I possess a specimen from the Pennystone Ironstone of Coalbrookdale.

*SCHIZODUS ANTIQUUS*, Hind. (Pl. XXXV, fig. 25.)

This specimen was also obtained by Mr. John Ward from below the Gin-Mine Coal at Longton.

The species ranges from the upper part of the Pendleside Series to the Coal-Measures. It also occurs above the Four-Foot Coal, Wetley Moor (North-Staffordshire Coalfield), and in the roof of the Bullion Mine, Carre Heys, Colne (Lancashire).

*LEIOPTERIA LONGIROSTRIS*, Hind. (Pl. XXXV, fig. 26.)

A single specimen, with the valves somewhat slipped on each other, has been found in a marine band with *Pterinopecten papyraceus* and *Pt. carbonarius*, 71 feet below the Four-Foot Coal in the Cheadle Coalfield.

The type-specimens of this species were obtained from one of the black limestones at the base of the Pendleside Series, Mam Tor, near Castleton. It is also found at Pendle Hill, Flasby Fell, and Horsebridge Clough, in beds of the same age.

*MYALINA COMPRESSA*, Hind. (Pl. XXXV, fig. 27.)

This species has now been obtained at several localities in the North-Staffordshire Coalfield, some few feet below the Moss Coal, in the Weston-Sprink marine band, and above the Seven-Foot Banbury. It also occurs 71 feet below the Four-Foot Coal of the Cheadle Coalfield, and at some horizons in South Staffordshire; also 80 feet below the Furnace Coal near Pilsley, in the Nottinghamshire Coalfield.

*SCALDIA MINUTA*, Hind. (Pl. XXXV, fig. 28.)

I described under this title<sup>1</sup> a little shell, which occurs in large numbers with other marine fossils.

Locality.—Marine band at Weston Sprink, near Longton (North-Staffordshire Coalfield).

<sup>1</sup> Trans. North Staffs. Nat. F.-C. vol. xxxiv (1899) p. 93.

### Cephalopoda.

In the determination of the cephalopoda I owe thanks for assistance to Dr. F. L. Kitchin, F.G.S., and Mr. G. C. Crick, F.G.S.

*EUPHEMUS* cf. *E. UREI*. (Pl. XXXVI, figs. 9 & 9 a.)

Several specimens which I refer to this species occur in the marine band below the Gin-Mine Coal at Nettlebank and Longton.

*GLYPHIOCERAS RETICULATUM* (Phillips). (Pl. XXXV, fig. 29.)

This species occurs at certain horizons in the Pendleside Series, in practically every locality in the Midlands where these beds occur. It is a shell which differs very much in outward appearance with regard to its age. Its aperture has a peculiar shape. The edge of the periphery is concave, making an acute angle with the margin, on either side; then a narrow lobe projects forward, below which the lateral margin is concave. In the young, the shell is strongly and coarsely ribbed; but in the adult, the ribs give place to fine sinuous striæ reticulated by fine spiral lines. *Glyphioceras bilingue* has a very similarly-shaped aperture.

*Glyphioceras reticulatum* occurs below the Gin-Mine Coal, Nettlebank (North Staffordshire).

*GLYPHIOCERAS PHILLIPSI* (?) Foord & Crick.<sup>1</sup> (Pl. XXXV, fig. 30.)

This is a species which occurs in the Pendleside Series of High-Green Wood, Hebden Bridge, Coldcoates, and at Foynes Island (Co. Limerick). It has never been found in the Carboniferous Limestone Series.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal at Nettlebank.

*GLYPHIOCERAS MICRONOTUM* (Phillips). (Pl. XXXV, fig. 31.)

This species is known from the Pendleside Series near Todmorden, and some of the British-Museum specimens are labelled 'Halifax'; but the exact horizon is not stated. This species does not seem to have so restricted a range as *Gl. Phillipsi*, for it is stated that specimens have been obtained from the Carboniferous Limestone Series of Wetton. Phillips quoted Bolland as the locality for his type. Unfortunately Bolland is the name of an extensive district, in which the Pendleside Series and the Carboniferous Limestone are both well developed. It may be pointed out that Wetton is situated on Carboniferous Limestone, of the white and grey varieties, containing a Viséan fauna; but the village is not far from the black limestones of the Pendleside Series. The matrix of the specimen from Wetton, which is No. C. 4399 in the National Collection at the British Museum (Natural History), will decide whether the specimen is from the Pendleside Series or no.

<sup>1</sup> Brit. Mus. Catal. Foss. Cephal. pt. iii (1897) p. 172.

*Glyphioceras micronotum* is a smooth compressed form: the inclusion is almost complete, and there is a very small umbilicus.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal.

GLYPHIOCERAS PAUCILOBUM (Phillips).

Dr. A. H. Foord has recognized this species in concretionary nodules which occur over the Seven-Feet Banbury seam. So far as I can ascertain, only one specimen of this species, probably the type, is in the National Collection at the British Museum (Natural History). The locality of the specimen was unfortunately not recorded.

J. W. Salter records the occurrence of this species from the Holcombe-Brook Series above the Second Coal (Millstone-Grit Series).<sup>1</sup>

DIMORPHOCERAS GILBERTSONI (Phillips). (Pl. XXXV, fig. 32.)

This species is, when well preserved, very finely marked with sinuous lines and ridges. It is much compressed, and has a minute umbilicus. Its maximum appears to be in the Pendleside Series. Its lowest appearance is in beds immediately succeeding the Carboniferous Limestone, alike in West Clare and in the Valley of the Hodder. It is also plentiful in the Lower Coal-Measures of Lancashire. Now, its range is extended much higher in the Coal-Measures. Mr. J. Neilson reports the occurrence of *Dimorphoceras Gilbertsoni* from the Lower Limestone Series of the West of Scotland.

Localities.—North-Staffordshire Coalfield: 71 feet below the Four-Feet Coal, Cheadle; below the Gin-Mine Coal, Nettlebank.

Lancashire Coalfield: above the Bullion Mine, Sholver. Pendleside Series: in 'bullions,' Horsebridge Clough, and Crimsworth Dean, near Todmorden; The Coombs, Leek (North Staffordshire).

GASTRIOCERAS CARBONARIUM (L. von Buch). (Pl. XXXVI, fig. 1.)

This species appears to have its maximum in the Lower Coal-Measures, but also occurs in the Pendleside Series at Horsebridge Clough, near Todmorden; and now we know it from the marine band below the Gin-Mine Coal in North Staffordshire. This species is also plentiful in the Upper Culm-Measures of Instow and Clovelly (Devon).

*Gastrioceras carbonarium* generally occurs in association with *G. Listeri* and *Dimorphoceras Gilbertsoni*; it is relatively somewhat more compressed, and its periphery is more convex than in *Gastrioceras Listeri*.

Localities.—North-Staffordshire Coalfield: below the Gin-Mine Coal; over the Stinking Coal, Cheadle.

Lancashire Coalfield: above the Bullion Coal and its equivalents.

<sup>1</sup> 'Geology of the Country around Bolton-le-Moors, Lancashire' Mem. Geol. Surv. 1862, p. 34.

Yorkshire Coalfield: above the Hard-bed Coal, Halifax. South-Wales Coalfield: under the Farewell Rock, Glan Rhymney.

In beds of Millstone-Grit age: Stibden (Yorkshire); Ipstones (Staffordshire).

*GASTRIOCERAS LISTERI* (Martin).

This species has only been noted by Mr. John Ward as occurring in the Cheadle Coalfield; but the specimens that he figured should be more correctly referred to *Gastrioceras carbonarium*. I have no personal knowledge of its occurrence in North Staffordshire.

*PLEURONAUTILUS COSTATUS*, sp. nov. (Pl. XXXVI, figs. 5, 5 a, & 5 b.)

Specific characters.—Shell discoidal, composed of three rapidly-enlarging, closely-applied, quadrate, ribbed whorls. Umbilicus large, showing nearly the whole of the whorls.

The whorl is almost square, but somewhat narrower at the periphery than at the umbilical margin; the periphery is very slightly concave, each margin being raised into a ridge, a character absent in the cast; the sides are very slightly concave above, convex below. The umbilical slope is smooth, moderately rapid, rounded in the young, subangular in the adult.

The body-chamber is large, and occupies apparently about one-third of a whorl. The aperture is not seen, but there must have been a broad and deep hyponomic sinus on the periphery. I can give no details of the chambers (camerae).

Siphuncle small, subcentral, somewhat nearer the periphery than the lower margin.

Nepionic stage not free, contiguous to the next whorl.

Ornament.—The shell is adorned with broad, arched costæ, separated by broad sulci, except over the body-chamber, which is smooth. These costæ rise on the umbilical margin of the whorl, and are somewhat swollen at the junction of the umbilical and lateral surfaces. They become broader and flatter, and arched somewhat forwards, and are inflated again at the junction of the lateral surface with the periphery. The costæ are more arched in the younger portion of the shell.

The sides of the shell are covered with minute lines of growth; on the periphery these lines show a deep, broad sinus with the concavity directed backwards. The nepionic stage is devoid of costæ, and has well-marked parallel striæ.

Dimensions.—The most complete specimen has a diameter of 84 millimetres.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal.

Observations.—This species is founded on one fairly-complete specimen and several fragments, casts, and crushed examples. I have compared them with *Pleuronautilus armatus* (Sow.) and *Pl. falcatus* (Sow.). In the former the costæ are fewer, more sigmoid; in the latter the costæ are more numerous and more regular in character,

without any tendency to become nodose. Another Coal-Measure example is *Pleuromutilus rotifer* (Salter), from the marine band at Ashton-under-Lyne, but this species seems to have more affinity to Sowerby's *Pl. falcatus* than to the Staffordshire specimen.

*PLEURONAUTILUS PULCHER*, Crick.<sup>1</sup> (Pl. XXXVI, fig. 3.)

This species has been very recently described by Mr. G. C. Crick, F.G.S., from specimens obtained from the Pendleside Series near Hebden Bridge. I have now to record the occurrence of the species in the Coal-Measures.

Locality.—North-Staffordshire Coalfield: 71 feet below the Four-Foot Coal, Cheadle.

*EPHIPPIOCERAS COSTATUM*, Foord.

Several fragments of this species have been found, showing the peculiar and characteristic suture-lines and the costate body-chamber, which distinguish the species from others. This species was already known from the Coal-Measures of Coalbrookdale, in the Pennystone Ironstone. It is found below the Gin Mine at Nettlebank (North Staffordshire).

NAUTILOIDS.

Several fragments of a form which probably belongs to *Temnocheilus*, bearing well-marked, short, conical tubercles along the margins of the periphery, have been obtained below the Gin-Mine Coal at Nettlebank. Unfortunately they are neither large enough, nor do they show details sufficiently well to determine the species; but the form is most probably new to Great Britain.

*TEMNOCHEILUS CARBONARIUS*, Foord. (Pl. XXXVI, fig. 4.)

Fragments which, I think, must belong to this species, occur in the marine band 71 feet below the Four-Foot Coal of Cheadle.

One fragment shows a broad periphery, and an angular margin, with elongate tubercles. The periphery has fine longitudinal lines crossing the deeply-sinuated lines of growth.

Dr. Foord's type, a fragment, is from Coalbrookdale (Shropshire). In the description he says:—

'A little below the border of the periphery there are three not very prominent and rather elongated nodes, with faint indications of two more towards the aperture.' (Brit. Mus. Catal. Foss. Cephal. pt. ii, 1891, p. 151.)

I possess a specimen from Coalbrookdale, consisting of the body-chamber and two septa, which shows on the body-chamber five nodes, and one other is faintly indicated near the aperture. The number of nodes is, therefore, not a specific character.

*TEMNOCHEILUS CONCAVUS* (Sow.).

Two fragments of the body-chamber may, I think, be safely referred to this species. They show the sulcus along the median

<sup>1</sup> Proc. Malacol. Soc. vol. vi (1904) pp. 15-20 & pl. ii.

part of the periphery and also a portion of the test, which exhibits a well-marked hyponomic sinus on the periphery. The siphuncle was placed a little way above the centre of the shell.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal. Coalbrookdale Coalfield: Pennystone Ironstone.

*SOLENOCHEILUS* aff. *CYCLOSTOMA* (Phill.). (Pl. XXXVI, figs. 2 & 2a.)

I refer to this species a fragment, the body-chamber of an adult shell, which has been found below the Gin-Mine Coal at Nettlebank. The siphuncle is seen to be near the peripheral margin. The periphery is broad, smooth, and convex, and has along its centre a fine raised line.

The impression of the preceding whorl is only moderately deep and narrow. The section of the whorl is circular when young, but is transverse in aged specimens.

I have met with this species below the Third Grit of Wadsworth Moor. Its vertical range is, therefore, much increased by the present discovery.

*CÆLONAUTILUS* cf. *SUBSULCATUS* (Phillips).

Two much-compressed fragments suggest reference to this species.

Locality.—North-Staffordshire Coalfield: below the Gin-Mine Coal. Yorkshire Coalfield: Shibden.

*ORTHO CERAS*.

At least two species of this genus occur below the Gin-Mine Coal of Nettlebank. One is small, elongate, and slender, and for the present I refer it to *O. asciculare*, Brown. Another fragment belongs to a much more robust species (Pl. XXXVI, fig. 8), with moderately-distant chambers and a slow rate of tapering, but it is too indefinite for the accurate determination of the species.

*ORTHO CERAS* aff. *ASCICULARE*, Brown.<sup>1</sup> (Pl. XXXVI, figs. 6 & 7.)

Localities.—North-Staffordshire Coalfield: below the Gin-Mine Coal, above the Crabtree Coal; 71 feet below the Four-Foot Coal, Cheadle.

Lancashire Coalfield: above the Bullion Mine, Sholver. Coalbrookdale Coalfield: Pennystone Ironstone.

Mr. George Wild figured a small slender *Orthoceras* from the Soapstone-bed, above the Bullion Coal, Trawden, Colne,<sup>2</sup> calling it *O. minutissimum*, Phillips. I think that this is Brown's species, the original of which came from the Pendleside Series near Todmorden. I have just figured specimens of this species from the Pendleside Series of the West of Ireland,<sup>3</sup> considering Baily's *O. minimum* as a synonym of Brown's shell. Probably *O. pygmæum*, de Koninck, from Chokier, belongs really to the same species. Apparently the Coal-Measure shell was much longer than those met with in the Pendleside Series.

<sup>1</sup> Trans. Manch. Geol. Soc. vol. i (1841) p. 220 & pl. vii, fig. 39.

<sup>2</sup> *Ibid.* vol. xxi (1891-92) p. 400 & pl. ii, fig. 4.

<sup>3</sup> Proc. Roy. Irish Acad. vol. xxv (1905) p. 112 & pl. vi, fig. 23.

LIST OF FOSSILS FROM THE MARINE BANDS  
IN THE COAL-MEASURES OF ENGLAND  
& WALES.

[NOTE.—The fishes in the marine bands,  
being only known from North Stafford-  
shire, are omitted here; for them, see  
the list on p. 529.]

ECHINODERMATA.

*Archæocidaris* sp. .... \*

ANNELIDA.

*Spirorbis* sp. nov. .... \*

ARTHROPODA.

*Dithyrocaris testudineum* .... \*

BRACHIOPODA.

*Ambocælia carbonifera*, sp. nov. .... \*

*Chonetes* aff. *laquessiana*, de Kon. .... \*

*Orbiculoidea nitida* (Phill.) .... \*

*Lingula mytiloides*, Sow. .... \*

*Productus anthrax*, sp. nov. .... \*

*Productus scabriculus* (Mart.) .... \*

*Productus*, scabriculocostate species .... \*

*Spirifer bisulcatus*, Sow. .... \*

*Rhipidomella Michelinii*, Lèveillé .. .. \*

LAMELLIBRANCHIATA.

*Aviculopecten gentilis*, Sow. .... \*

*Pseudamusium fibrillosum* (Salter) .... \*

*Syncyclonema carboniferum*, Hind .... \*

*Pterinopecten carbonarius*, Hind .... \*

*Pterinopecten papyraceus* (Sow.) .... \*

*Posidoniella lævis* (Brown) .... \*

*Posidoniella minor* (Brown) .... \*

*Posidoniella sulcata*, Hind .... \*

*Leiopteria longirostris*, Hind .... \*

*Myalina compressa*, Hind .... \*

*Schizodus antiquus*, Hind .... \*

*Schizodus axiniiformis*, Sow. .... \*

*Schizodus carbonarius*, Sow. .... \*

*Nucula æqualis*, Sow. .... \*

*Nucula gibbosa*, Flem. .... \*

*Nucula oblonga*, M'Coy .... \*

*Nuculana acuta* (Sow.) .... \*

*Nuculana Sharnani*, R. Eth. fil. .... \*

*Ctenodonta levirostris* (Porl.) .... \*

*Ctenodonta undulata* (Phill.) .... \*

*Scaldia minuta*, Hind .... \*

*Edmondia accipiens*, Sow. .... \*

*Edmondia* aff. *laminata*, Phill. .... \*

*Edmondia senilis*, Phill. .... \*

*Allorisma Ansticei*, Sow. .... \*

*Solenomya primæva*, Phill. .... \*

NORTH STAFFORDSHIRE.

SOUTH STAFFORDSHIRE.

COALBROOKDALE.

LEICESTERSHIRE.

SOUTH WALES.

FLINTSHIRE & DENBIGH-  
SHIRE.

LANCASHIRE.

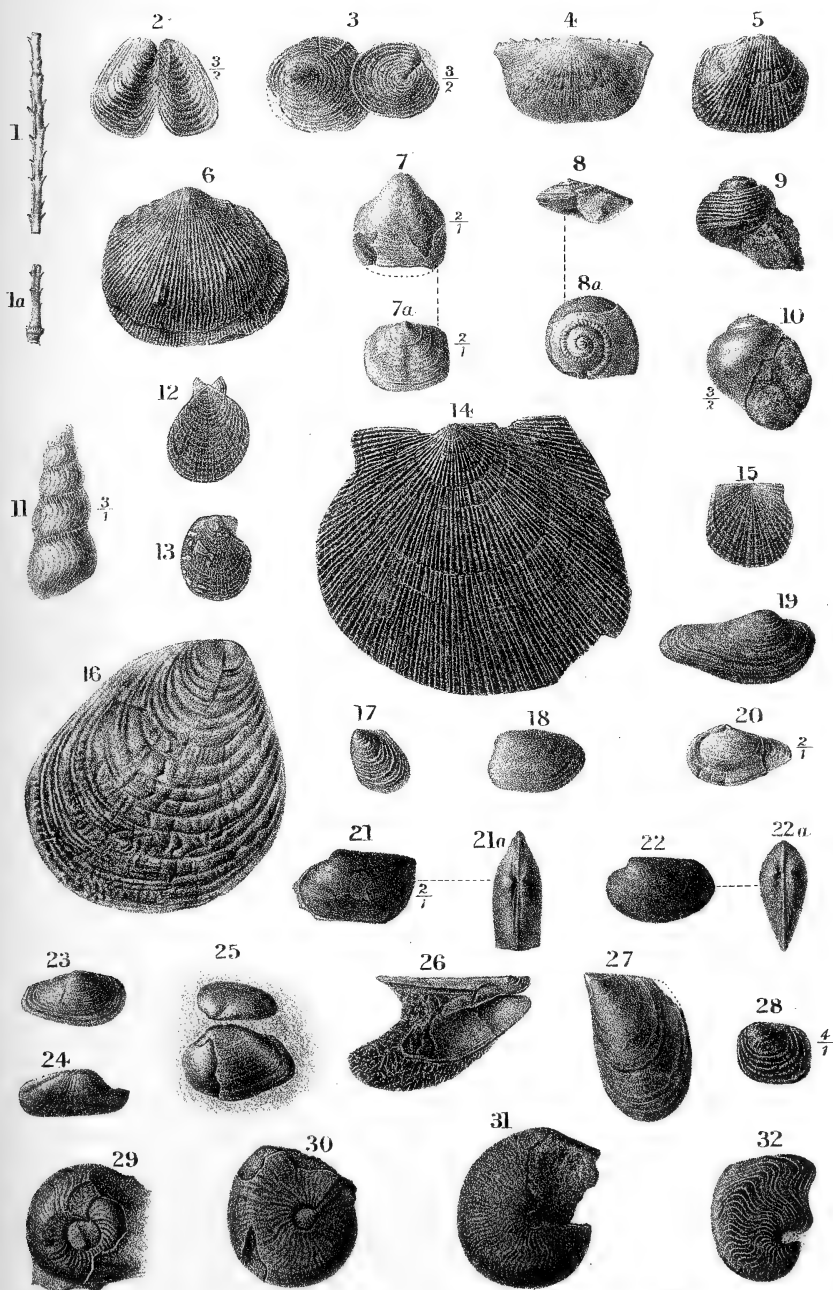
DURHAM.

YORKSHIRE, DERBYSHIRE,  
& NOTTINGHAMSHIRE.

LIST OF FOSSILS FROM THE MARINE BANDS  
IN THE COAL-MEASURES OF ENGLAND  
& WALES (continued).

	NORTH STAFFORDSHIRE.	SOUTH STAFFORDSHIRE.	COALBROOKDALE.	LEICESTERSHIRE.	SOUTH WALES.	FLINTSHIRE & DENBIGH- SHIRE.	LANCASHIRE.	DURHAM.	YORKSHIRE, DERBYSHIRE, & NOTTINGHAMSHIRE.
<b>GASTEROPODA.</b>									
<i>Raphistoma (?) ornata</i> , Bolton .....	..	..	..	..	..	..	*		
<i>Raphistoma radians</i> , de Kon. ....	..	..	..	..	..	..	*		
<i>Turbonellina formosa</i> , de Kon. ....	*								
<i>Naticopsis brevispira</i> (de Ryck.) .....	*								
<i>Naticopsis globularis</i> , Bolton .....	..	..	..	..	..	..	*		
<i>Loxonema acutum</i> , de Kon. ....	*								
The following are described in Prestwich's memoir on Coalbrookdale:—									
<i>Globulus vetustus</i> , Sow. ....	..	..	*						
<i>Littorina (?) obscura</i> , Sow. ....	..	..	*						
<i>Turritella (?) clavata</i> .....	..	..	*						
<i>Turritella (?) minima</i> , Sow. ....	..	..	*						
<i>Polyphemus (?) fusiformis</i> , Sow. ....	..	..	*						
<i>Trochus (?) usocona</i> , Sow. ....	..	..	*						
<b>CEPHALOPODA.</b>									
<i>Ephippioceras clitellarium</i> (Sow.) .....	..	..	*			..	*		
<i>Ephippioceras costatum</i> , Foord .....	*	..	*			..	*		
<i>Euphemus Urei</i> .....	*								
<i>Calonautilus quadratus</i> , Flem. ....	..	..	*			..	*		
<i>Calonautilus cf. subsulcatus</i> (Phill.) .....	*	..				..	*		*
<i>Pleurodontilus armatus</i> (Sow.) .....	..	..	*						
<i>Pleurodontilus costatus</i> , sp. nov. ....	*								
<i>Pleurodontilus falcatus</i> (Sow.) .....	..	..	*	..	*				
<i>Pleurodontilus pulcher</i> , Crick .....	*								
<i>Pleurodontilus rotifer</i> (Salter) .....	..	..				..	*		
<i>Temnocheilus carbonarius</i> , Foord .....	*	..	*			..	*		
<i>Temnocheilus concavus</i> (Sow.) .....	*	..	*		*	..	*		
<i>Temnocheilus tuberculatus</i> (Sow.) .....	..	..	*			..	*		*
<i>Solenoceras aff. cyclostoma</i> (Phill.) .....	*								
<i>Solenoceras</i> sp. ....	..	..				..	*		*
<i>Glyphioceras micronotum</i> (Phill.) .....	*	..				..	?		
<i>Glyphioceras paucilobum</i> (Phill.) .....	*	..				..	*		
<i>Glyphioceras Phillipsi</i> , Foord & Crick .....	*	..				..	*		
<i>Glyphioceras reticulatum</i> (Phill.) .....	*	..				..	*		
<i>Dimorphoceras discrepans</i> (Phill.) .....	..	..				..	*		
<i>Dimorphoceras Gilbertsoni</i> (Phill.) .....	*	..				..	*		
<i>Dimorphoceras Looyi</i> (Phill.) .....	..	..				..	*		
<i>Nomismoceras ornatum</i> , Foord & Crick ..	..	..				..	*		
<i>Gastrioceras carbonarium</i> (L. von Buch) ..	*	..	..	*		..	*	..	*
<i>Gastrioceras coronatum</i> , Foord & Crick ..	..	..				..	*		
<i>Gastrioceras Listeri</i> (Martin) .....	..	..				..	*		*
<i>Orthoceras aff. asculare</i> , Brown .....	*	..	..	*		..	*		*
<i>Orthoceras scalpratum</i> , Sow. ....	..	..	*			..			
<i>Orthoceras Steinhaueri</i> , Sow. ....	..	..				..	*		
<i>Orthoceras</i> sp. ....	*								
<i>Conularia quadrisulcata</i> , Sow. ....	..	*	*	..	*				





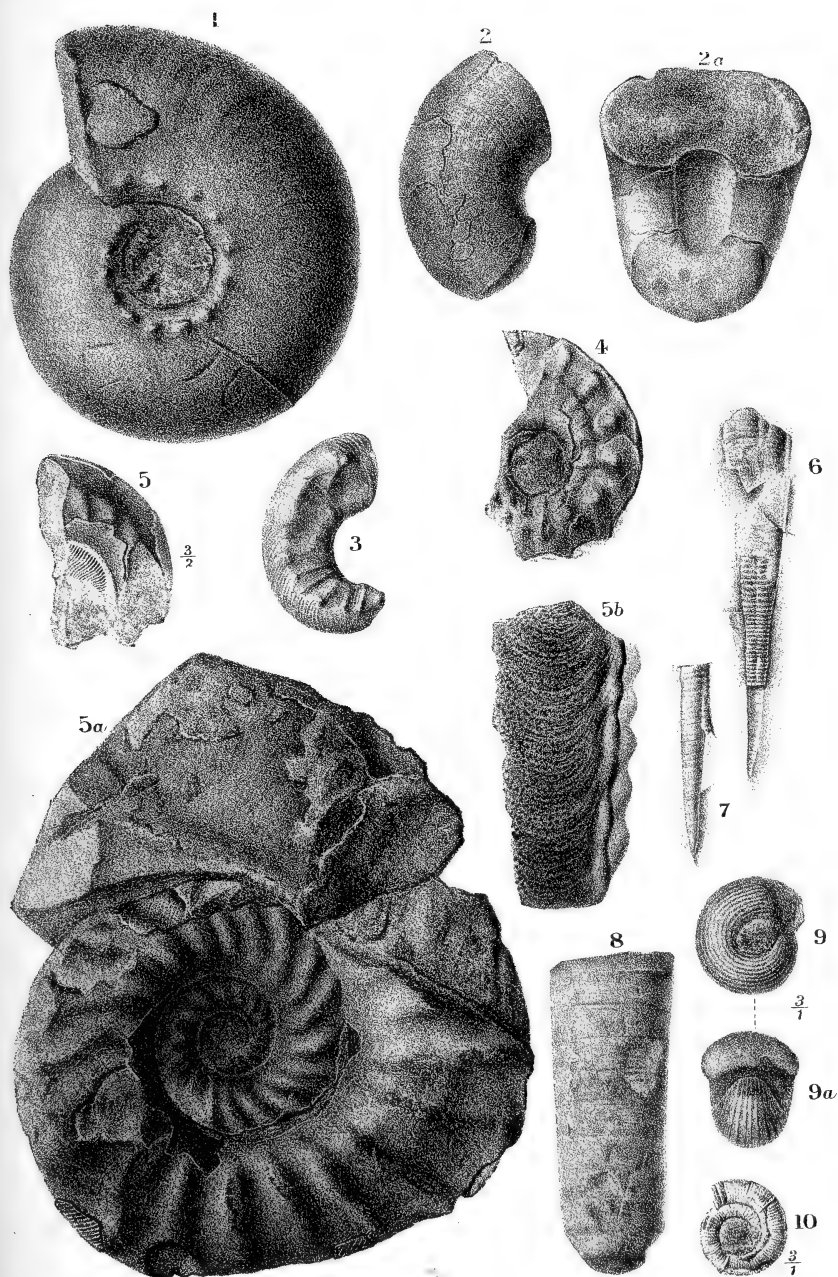
A.H. Searle del. et. lith.

Bale & Danielsson Ltd imp.

# MARINE FOSSILS

From the Coal-Measures of North Staffordshire.





A.H. Searle del. et lith.

Bale & Danielsson Ltd imp.

# MARINE FOSSILS

From the Coal-Measures of North Staffordshire.



## EXPLANATION OF PLATES XXXV &amp; XXXVI.

[The figures are of the natural size, unless otherwise stated.]

## PLATE XXXV.

- Figs. 1 & 1 a. Radiole of *Archæocidaris*, sp. Below the Gin-Mine Coal, Nettlebank. (See p. 529.)
- Fig. 2. *Lingula mytiloides*.  $\times \frac{3}{2}$ . Above the Moss Coal, Longton Hall. (See p. 529.)
3. *Orbiculoidea nitida*.  $\times \frac{3}{2}$ . Above the Lady or Bay Coal, Chell. (See p. 530.)
4. *Chonetes laqueusiana*, mut.  $\theta$ . Below the Gin-Mine Coal, Nettlebank. (See p. 530.)
5. *Productus*, scabriculocostate form. Below the Gin-Mine Coal, Longton. (See p. 531.)
6. *Productus anthrax*, sp. nov. Below the Gin-Mine Coal, Nettlebank. (See p. 531.)
- Figs. 7 & 7 a. *Ambocalia carbonaria*.  $\times 2$ . Pedicle and brachial valves. Same locality. (See p. 531.)
- 8 & 8 a. *Raphistoma radians*. Same locality. (See p. 532.)
- Fig. 9. *Turbonellina formosa*. Same locality. (See p. 532.)
10. *Naticopsis brevispira*.  $\times \frac{3}{2}$ . Same locality. (See p. 533.)
11. *Loxonema acutum*.  $\times 3$ . Same locality. (See p. 533.)
12. *Synceylonema carboniferum*. Same locality. (See p. 534.)
13. *Pseudamysium fibrillosum*. Same locality. (See p. 534.)
14. *Pterinopecten papyraceus*. 71 feet below the Four-Foot Coal, Cheadle. (See p. 534.)
15. *Pterinopecten carbonarius*. Same locality. (See p. 534.)
16. *Posidoniella sulcata*. Below the Gin-Mine Coal, Nettlebank. (See p. 535.)
17. *Posidoniella levis*. 71 feet below the Four-Foot Coal, Cheadle. (See p. 535.)
18. *Nucula gibbosa*. Below the Gin-Mine Coal, Nettlebank. (See p. 536.)
19. *Nuculana Sharmani*. Same locality. (See p. 536.)
20. *Nuculana acuta*.  $\times 2$ . Same locality. (See p. 536.)
- Figs. 21 & 21 a. *Nucula oblonga*.  $\times 2$ . Same locality. (See p. 536.)
- 22 & 22 a. *Ctenodonta undulata*. Below the Gin-Mine Coal, Longton. (See p. 537.)
- Fig. 23. *Ctenodonta lævirostris*. Below the Gin-Mine Coal, Nettlebank. (See p. 536.)
24. *Solenomya primæva*. Below the Gin-Mine Coal, Longton. (See p. 537.)
25. *Schizodus antiquus*. Same locality. (See p. 537.)
26. *Leiopteria longirostris*. 71 feet below the Four-Foot Coal, Cheadle. (See p. 537.)
27. *Myalina compressa*. Same locality. (See p. 537.)
28. *Scaldia minuta*.  $\times 4$ . Weston Sprink. (See p. 537.)
29. *Glyphioceras reticulatum*. Below the Gin-Mine Coal, Nettlebank. (See p. 538.)
30. *Glyphioceras Phillipsi*. Same locality. (See p. 538.)
31. *Glyphioceras micronotum*. Same locality. (See p. 538.)
32. *Dimorphoceras Gilbertsoni*. 71 feet below the Four-Foot Coal, Cheadle. (See p. 539.)

## PLATE XXXVI.

- Fig. 1. *Gastrioceras carbonarium*. Below the Gin-Mine Coal, Nettlebank. (See p. 539.)
- Figs. 2 & 2 a. *Solenocheilus* aff. *cyclostoma*. Same locality. (See p. 542.)
- Fig. 3. *Pleuromutilus pulcher*. Same locality. (See p. 541.)
4. *Temnocheilus carbonarius*. Same locality. (See p. 541.)
5. *Pleuromutilus costatus*,  $\times \frac{3}{2}$ . Showing nepionic stage. Same locality. (See p. 540.)
- 5 a. *Pleuromutilus costatus*. Same locality. (See p. 540.)
- 5 b. *Pleuromutilus costatus*, showing periphery. Same locality.

Figs. 6 & 7. *Orthoceras* aff. *asciculare*. Same locality. (See p. 542.)

Fig. 8. *Orthoceras*, sp. Same locality. (See p. 542.)

Figs. 9 & 9 a. *Euphemus* cf. *Urei*.  $\times 3$ . Same locality. (See p. 538.)

Fig. 10. *Spirorbis*, sp.  $\times 3$ . Same locality. (See p. 502.)

#### DISCUSSION.

THE PRESIDENT said that he welcomed the paper, as adding a number of new facts to those which we already possessed. The paper was an example of those which (themselves concerned with pure science) were nevertheless likely to be of much economic value. He was glad to hear the Authors bring forward what appeared to be conclusive evidence that *Naiadites*, *Carbonicola*, and *Anthracomya* did not occur in association with the marine forms.

MR. WALCOT GIBSON congratulated the Authors on an important piece of work which had a practical bearing, especially on the question of determining one's position in the Coal-Measure sequence in concealed areas. He did not think that the presence of *Lingula* alone was a safe index of position in the absence of other data. He would like to ask Mr. Stobbs in what sense he used the term 'true Coal-Measures.'

DR. TEALL associated himself fully with the complimentary remarks which had been made on the paper, but said that he had not quite gathered what were the main features upon which the Authors relied for the identification of particular marine bands. He enquired whether they relied on the limitation of the range of some particular forms, or on the general association.

PROF. P. F. KENDALL desired to associate himself with the expression of approval which had fallen from previous speakers. The Authors were engaged upon a piece of work, the progress of which he and other geologists in Yorkshire were watching with the keenest interest and gratification, and he expressed the hope that they would extend their researches to the coalfields on the eastern side of the Pennine Chain.

He remarked that the arguments which had been employed to prove that there were two molluscan faunas in the Coal-Measures, one marine and the other containing *Anthracosia* of freshwater habitat, were employed by Green in his monumental memoir on the Geology of the Yorkshire Coalfield. One apparent exception, to the rule that marine fossils never occurred in association with the *Anthracosia*-group of shells, was recorded in the case of the Thin Coal, which lies almost immediately upon the Rough Rock; but further research in more accessible sections showed that the *Anthracosia*-Band formed the true roof of the seam, and was covered in its turn by shale containing marine organisms. In Yorkshire, marine bands occurred in nearly all the larger shale-beds of the Millstone Grit, from the top of the Kinderscout Grit to the shale immediately underlying the Rough Rock; but in the Coal-Measures only two or three marine horizons had been recognized: one of these was just above the Thin Coal, and another formed the roof of the Gannister Coal.

Regarding the correlation of the coal-seams upon opposite sides of the Pennine Chain, it should be borne in mind that the recognition of the identity of the Silkstone Seam of Yorkshire with the

Arley Mine of Lancashire was made at least as long ago as the publication of Green's memoir, and probably much earlier. The identity of the Gannister Coal with the Bullion Mine of Lancashire was established by the clearest evidence. The Gannister or Halifax Hard Coal was characterized throughout Yorkshire by its hard sandstone-floor, by the roof of shale with marine organisms, and by the occurrence (within the seam itself) of hard nodules containing perfectly-preserved plant-structures. In Lancashire, it was characterized in the same manner; and it was very gratifying to learn that the Authors had established the fact of its extension into North Staffordshire.

Dr. F. A. BATHER, responding to Dr. Wheelton Hind's request that he should say something about the fragments of *Archæocidaris*, pointed out that these consisted of radioles, tuberculate interambulacral plates, and teeth. The teeth and plates appeared to be different from those belonging to *A. Urei* and *A. scotica*. Among other species from Britain or Belgium, comparison was only possible with *A. vetusta*, Phillips, and *A. benburbensis*, Portlock, two forms which McCoy regarded as a single species. Although these radioles differed in several features from *A. benburbensis*, the speaker had declined to give them a new name, until he had been able to study specimens which could safely be determined as *A. vetusta*, for the interpretation of which Phillips's description was quite insufficient. The occurrence of this genus was interesting, since, although common enough in the Coal-Measures of North America, it was not so in this country; further, echinoids were certain proof of the existence of thoroughly salt-water conditions.

Mr. STOBBS, in reply to Mr. Walcot Gibson's remarks concerning the use of the term 'true Coal-Measures,' said that he knew of no other convenient name for the important sequence of Coal-Measures from the Millstone Grit to the base of the thick—and so far as workable coal-seams were concerned—barren, overlying Coal-Measures, as developed in the Midlands. Whether shales containing *Lingula* only were to be regarded as strictly marine or not, did not affect the utility of the horizon for purposes of stratigraphy, provided that the fauna was distinct and unmixed with other forms of freshwater character, and that the band was persistent; and experience in North Staffordshire showed that they might expect these conditions to hold.

With reference to Dr. Teall's query as to the evidence upon which the Authors relied for the correlation of a marine band in one coalfield with a similar horizon in another coalfield, sometimes the striking character of the fauna in each instance was sufficient in itself. In other cases, in addition to the marine fossils, the Authors observed the relative position of the bed in the series, and its proximity to one of those zones of freshwater mollusca which had been established by Dr. Wheelton Hind; but the speaker fully admitted that caution was necessary in this matter. He thanked the Fellows for the reception accorded to the paper.

Dr. WHEELTON HIND said that the fossil-horizons were recognized by their aggregate contents, and by the relations of the marine bands to others containing definite species of *Carbonicola* and *Anthracomya*.

25. *The CARBONIFEROUS LIMESTONE of the WESTON-SUPER-MARE DISTRICT (SOMERSET).* By THOMAS FRANKLIN SIBLY, B.Sc. (Communicated by Dr. ARTHUR VAUGHAN, B.A., F.G.S. Read May 10th, 1905.)

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## I. INTRODUCTION.

WESTON-SUPER-MARE lies  $16\frac{1}{2}$  miles W.  $25^{\circ}$  S. of Clifton Suspension-Bridge. The Carboniferous Limestone in the neighbourhood forms two ridges which stand up prominently from the surrounding alluvial flats. The southern ridge, which I term the Weston-Worle ridge, runs a little north of east from the coast, at Weston, to Worle, and is about 3 miles in length. The northern and smaller ridge, known as Middle Hope (the Woodspring ridge), lies 2 miles farther north, is about 2 miles in length, and runs almost parallel to the Weston-Worle ridge.

The occurrence of contemporaneous igneous rocks associated with the Carboniferous Limestone both at Weston and at Middle Hope, lends especial interest to the district. The igneous rocks have been described by Sir Archibald Geikie and Mr. Aubrey Strahan,<sup>1</sup> and also, more fully, by Prof. C. Lloyd Morgan & Prof. S. H. Reynolds.<sup>2</sup> The Spring-Cove lava (Weston) has, further, been fully described by Prof. W. S. Boulton.<sup>3</sup>

The present paper is devoted chiefly to a detailed description of the Weston-Worle ridge. My object in examining the district was an investigation of the coral- and brachiopod-succession in the Carboniferous Limestone, in connection with my work in the Mendip area, and in continuation of the work accomplished by Dr. Arthur Vaughan<sup>4</sup> in the Bristol area. In order to accomplish this with thoroughness in the Weston-Worle ridge, much detailed stratigraphical work has been necessary, owing to the fact that faulting and resultant folding have complicated the structure of the ridge.

<sup>1</sup> 'Summary of Progress of the Geological Survey for 1898' pp. 104-11.

<sup>2</sup> 'The Igneous Rocks associated with the Carboniferous Limestone of the Bristol District' Quart. Journ. Geol. Soc. vol. lx (1904) pp. 137 *et seqq.*

<sup>3</sup> *Ibid.* pp. 158 *et seqq.*

<sup>4</sup> See 'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area' Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 181 *et seqq.*



Both the stratigraphy and the faunal sequence are dealt with fully in this paper. The determination of the stratigraphical features of the Limestone has been rendered easier by the palæontological work: this affords an illustration of the advantage of relying on the assemblage of corals and brachiopods for the approximate determination of horizons in the Carboniferous Limestone.

The structural features of the Woodspring ridge do not call for special attention, and are, therefore, treated briefly. A comprehensive account of the faunal sequence displayed there is given.

The geographical position of the Carboniferous Limestone of the Weston district, lying as it does adjacent to the Bristol area, on the north-east, and the Mendip area, on the south-east, suggests the probability of an intermediate type of development being found there; and this suggestion has been verified by the examination of the district. A comparison with neighbouring areas is appended to the detailed part of the paper.

In carrying out my work, I have received much encouragement and assistance from other geologists. I am deeply indebted to Dr. Arthur Vaughan, Prof. C. Lloyd Morgan, and Prof. S. H. Reynolds, for their advice and encouragement. I wish to thank Dr. Vaughan for his continual and ungrudging assistance in the palæontological work; to Mr. F. P. Burt I am indebted for much assistance in the field; and I owe the photograph (fig. 3) illustrating this paper to the kindness of Prof. S. H. Reynolds.

SYNOPSIS OF THE ZONES AND SUBZONES OF THE CARBONIFEROUS LIMESTONE  
REPRESENTED IN THE WESTON-SUPER-MARE DISTRICT.

Zones.	Subzones and Horizons.	Symbols.
SEMINULA .....	{ <i>Productus</i> aff. <i>Cora</i> (mut.) .....	S <sub>2</sub>
	{ <i>Productus semireticulatus</i> (mut.) .....	S <sub>1</sub>
SYRINGOTHYRIS.....	{ [Upper] .....	C <sub>2</sub>
	{ [Lower] .....	C <sub>1</sub>
	Horizon γ.	
ZAPHRENTIS .....	<i>Schizophoria resupinata</i> .....	Z <sub>2</sub>

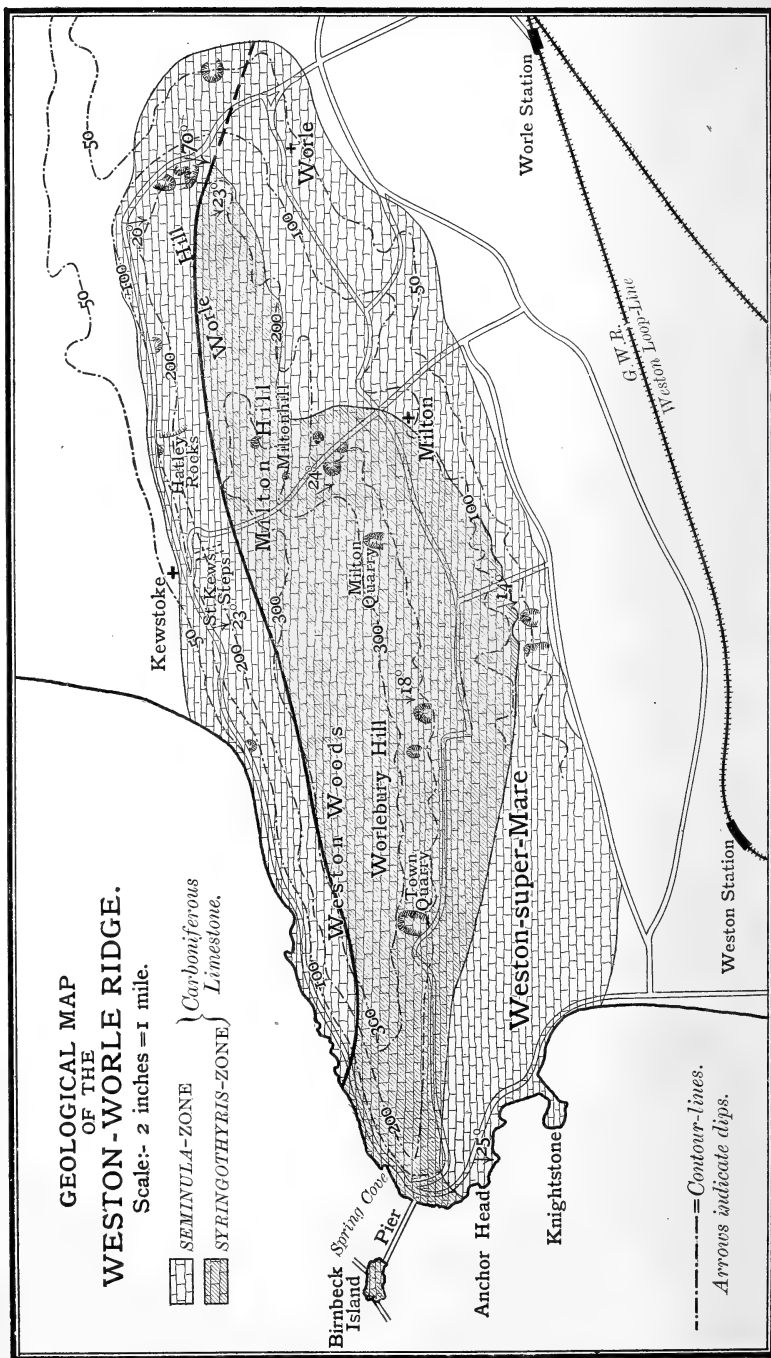
## II. THE WESTON-WORLE RIDGE.

### (1) Topography and General Stratigraphy.

The Carboniferous Limestone in the immediate neighbourhood of Weston-super-Mare forms a bold ridge, some 3 miles in length, which runs in a direction nearly 15° north of east from the coast, at Weston, to Worle, and rises to a maximum height of about 350 feet above sea-level near the middle of its length. The average height of the top of the ridge is rather over 300 feet, and the out-crop of the Carboniferous Limestone has a fairly-constant width of nearly a mile.

The various parts of the ridge, taking them in order eastward from Weston, are respectively called: Worlebury Hill (with Worlebury Camp at the western end), Milton Hill, and Worle Hill. The

Fig. 1.—Geological map of the Weston-Worle ridge, based on the 6-inch maps of the Ordnance Survey.



[The heavy black line indicates the course of the fault. The map is oriented north and south.]

greater part of the hill, for over a mile east of Worlebury Camp, is covered by Weston Woods.

Throughout the ridge the beds dip in a southerly direction; consequently, the northern side forms a steep escarpment. On the southern side, the ground drops steeply for about 150 feet, but afterwards slopes away more gently to the alluvial flats which lie between Weston and the Mendips.

The general structure of the ridge is simple. A reversed fault, running the whole length of the hill, has thrown beds of *Syringothyris*-age, on the south, against beds of *Seminula*-age, on the north. The throw of this fault cannot be determined with accuracy, but it is not much less than 500 feet, and probably greater rather than less.

Considerable variation in the dip and strike of the beds, such as would naturally be expected in the neighbourhood of a large fault, is noted on traversing the ridge from end to end. On the coast north of Weston, the 'laminosa-dolomites' [Lower *Syringothyris*-Zone,  $C_1$ ] are in juxtaposition with Lower *Seminula*-Beds [ $S_1$ ] at the fault. The general strike between Weston and Milton Hill approximates to east and west, and on the western part of Milton Hill the fault comes out at about the same level in the *Syringothyris*-Zone. Eastward from Milton Hill, however, the east-northeasterly trend of the strike causes the beds of the *Syringothyris*-Zone to successively overlap each other against the fault, and, consequently, Upper *Syringothyris*-Beds [ $C_2$ ] come into contact with Upper *Seminula*-Beds [ $S_2$ ] at the eastern end of Worle Hill.

South of the fault there is a complete sequence from  $C_1$  to  $S_2$ . The lowest beds seen form the upper part of the 'laminosa-dolomites,' and are exposed on the coast, north of Weston; they lie some 500 feet below the top of the *Syringothyris*-Zone. The highest beds anywhere exposed occur at Knightstone; these lie well up in  $S_2$ , and roughly about 1000 feet above the 'laminosa-dolomites.'

North of the fault only the *Seminula*-Zone is represented. Beds near the base of  $S_1$  are seen on the coast, between Weston and Kewstoke; the highest beds represented, which are quarried at the eastern end of Worle Hill, belong to  $S_2$ .

An obvious result of the fault is seen in a large overfold of the *Seminula*-Beds, on the north side of the fault. This fold can be made out in the quarries at the eastern end of the ridge, and traced westward for about two-thirds of a mile; at a distance of about a mile it apparently dies out.

No good continuous section occurs anywhere in the ridge, the coast-section being in a very unsatisfactory condition for examination. But certain parts of the sequence, notably the Upper *Syringothyris*-Zone, on the south side of the hill, are extensively quarried and are, therefore, well exposed for examination.

## (2) Detailed Stratigraphy.

## (a) The Area South of the Fault.

(i) The coast-section.—Along the coast, from north to south, between the fault, some 400 yards E.  $30^{\circ}$  N. of Spring Cove, and Knightstone, there is a section extending from the Lower *Syringothyris*-Zone [C.] into the Upper *Seminula*-Zone [S<sub>2</sub>]. This section is continuous as far as the base of S<sub>2</sub>, but a large gap is caused in S<sub>2</sub> by Glentworth Bay. The dip and strike of the beds vary slightly throughout the section, the mean dip being about  $25^{\circ}$  in a direction approximating to due south. The extremely-weathered condition of the rocks renders the section unsatisfactory for examination, and the faunal sequence cannot, therefore, be made out with much completeness; but the general succession may be determined, by means of the fossils recorded from various levels.

*SYRINGOTHYRIS*-ZONE.—Beds having a total vertical thickness of rather over 500 feet, and extending from the fault as far as the cliff under the Royal Pier Hotel, may be assigned to this zone.

At the fault, we find fossiliferous beds of the Lower *Seminula*-Zone in juxtaposition with dolomitic limestones, which are apparently unfossiliferous. These latter beds form the upper part of the 'laminosa-dolomites,' and are succeeded by comparatively-unfossiliferous, very oolitic limestones (=the 'Caninia-Oolite'), which extend to within a few yards of Spring Cove.

Above this, a thick series of fossiliferous limestones, generally oolitic, especially in the upper part, extends to the top of the zone. A break is caused by the Spring-Cove volcanic series, which lies about 450 feet below the top of the zone, and very near the base of the fossiliferous limestones.

Parts of this fossiliferous sequence are further exposed: (1) on the north side of Worlebury Camp; (2) in the mural face above the Kewstoke Road, a little west of the Tollgate; (3) in the Gardens above the Royal Pier Hotel.

*SEMINULA*-ZONE.—Fossiliferous beds in the cliff under the Claremont Hotel may be regarded as lying approximately at the base of this zone. They are succeeded by ironstained limestones, which are apparently unfossiliferous, exposed in Madeira Cove and at Anchor Head. Above these again come fossiliferous, ironstained limestones, exposed on the foreshore under Claremont Crescent; these beds may be considered to terminate S<sub>1</sub>, which has a total thickness of about 170 feet.

S<sub>2</sub> is very poorly displayed. The basal beds, consisting of highly-fossiliferous limestones, are exposed under the Esplanade, on the north side of Glentworth Bay. Then follows a gap, caused by the sandy bay, in which some 300 feet of the sequence is lost. Finally, at Knightstone, on the south side of the bay, fossiliferous, oolitic limestones are seen, and these terminate the section.

(ii) The *Syringothyris*-Zone as exposed on the south side of the ridge.—The lower part of this zone is nowhere

exposed inland. This is due to (1) the eastward extension of Weston Woods, for over a mile and a half; and (2) the absence of exposures to the north of the track which runs along the crest of Milton Hill. Nevertheless, conclusive evidence of the easterly extension of the Spring-Cove lava has been obtained by other workers, and, as will be seen, this agrees with my own determination of the stratigraphical features of the Upper *Syringothyris*-Beds.

Fossiliferous limestones, included in the upper 300 feet of the zone, are exposed in a continuous series of quarries and hillside exposures, lying approximately on a line of strike, and extending from the Town Quarry, above Weston, eastward to the slopes under Worle Tower. Proceeding eastward, the exposures of this series are as follows :—

- (1) The Town Quarry.
- (2) A small quarry about 100 yards east of the Town Quarry.
- (3) Numerous exposures along the north side of Cecil Road.
- (4) A small quarry in the woods, above Eastfield Park.
- (5) A disused quarry on the edge of the woods, a little west of Ashcombe Wood.
- (6) Milton Quarry.
- (7) Four quarries near the road leading from Milton up to Miltonhill; two of these lie on the right of the road, and two on the left.
- (8) A quarry on Milton Hill. This lies on the top of the hill, about 300 yards along the track leading from Miltonhill to Worle Tower, and just above Ranscombe House.
- (9) A series of hillside exposures and small disused quarries, extending from Milton Hill to the slopes south of Worle Tower.

Along the hill above Weston, the strike of the beds is approximately east and west, but in the neighbourhood of Milton Hill it has shifted to within a few degrees of north-east and south-west. Consequently, as we proceed eastward, higher and higher parts of the series overlap each other against the fault (which runs a little north of east), and the lower beds of the series do not extend far beyond the quarry on Milton Hill.

In this connection we come to some interesting conclusions with regard to the easterly extension of the Spring-Cove igneous rocks. It is evident that the lava, which occurs low down in the *Syringothyris*-Zone, cannot extend east of Milton Hill; and this conclusion is fully borne out by the observations of those geologists who have paid special attention to the igneous rocks.<sup>1</sup>

The easternmost exposure of the *Syringothyris*-Beds, which shows beds very near the top of the zone, occurs in the lane leading from Worle Tower to the road.

The fault can be located near the sharp bend in this lane, about 280 yards E. 20° S. of Worle Tower. Upper *Syringothyris*-Beds lie south-west of this point, while Upper *Seminula*-Beds appear immediately to the north-east.

<sup>1</sup> Sir A. Geikie & A. Strahan, 'Summary of Progress of the Geological Survey for 1898' p. 106; and C. Lloyd-Morgan & S. H. Reynolds, 'The Igneous Rocks associated with the Carboniferous Limestone of the Bristol District' Quart. Journ. Geol. Soc. vol. lx (1904) pp. 145, 146.

(iii) Isolated exposures in the *Seminula-Zone*.

- (1) A good exposure of beds assigned to the base of this zone occurs, high up on the right-hand side of the narrow valley which furrows the side of Milton Hill, in an east-southeasterly direction, below Ranscombe House.
- (2) A horizon near the base of  $S_1$  is well exposed in two adjoining quarries, lying a little north of Milton Road, between Manor Road and Ashcombe Park Road, at the eastern end of the town. The beds displayed are extremely fossiliferous, and have yielded an abundant and interesting brachiopod- and coral-fauna.
- (3) Several small exposures in the village of Worle and its immediate neighbourhood furnish evidence of the eastward extension of the *Seminula-Zone*.

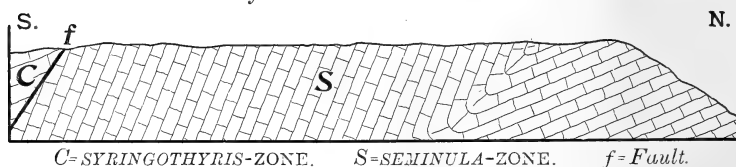
## (b) The Area North of the Fault.

The beds represented on the north side of the fault all belong to the *Seminula-Zone*.

In the western half of the area, between the fault, on the coast, and St. Kew's Steps, the exposures are few and not very good. The beds, which are all included in  $S_1$ , have a general strike of about E.  $17^\circ$  N. The coast-section extends rather more than 1000 yards eastward from the fault; but, since the coast-line runs practically parallel to the strike, the thickness of beds exposed is small. In this section, the upper beds are fossiliferous limestones; the lower beds are comparatively-unfossiliferous ironstained limestones. The former can be seen in several small exposures along the Kewstoke Road, running through Weston Woods, and in a small roadside quarry, about 500 yards west of the Kewstoke Tollgate. In the escarpment above the Tollgate, the upper part of  $S_1$  is exposed.

In the eastern half of the area, the exposures are somewhat better. The highest beds represented [ $S_2$ ] are exposed in three quarries lying close together under the eastern end of Worle Hill. The effect of the fault is clearly displayed at this level by an overfold of the beds, which can be interpreted by an examination of the quarries. The accompanying section (fig. 2) illustrates this fold.

Fig. 2.—Section across the eastern end of Worle Hill, showing the overfold in the *Seminula-Beds*.



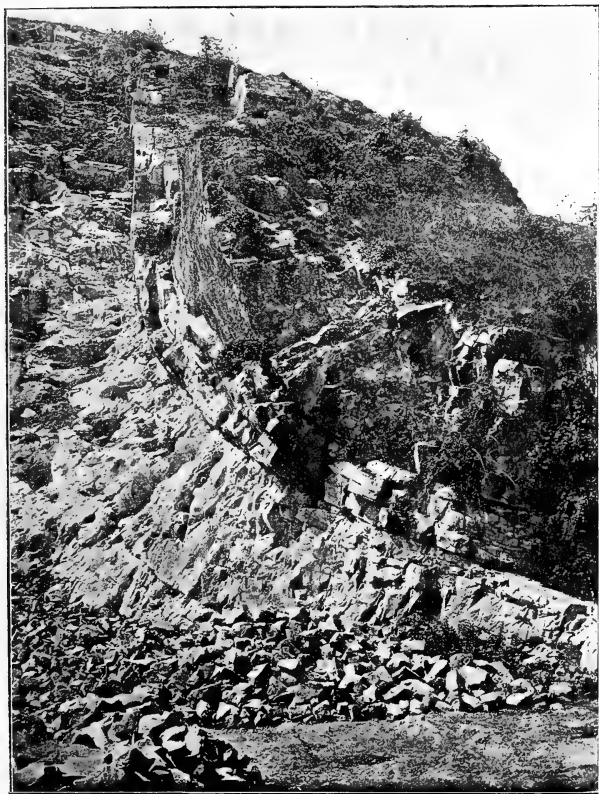
[Length of section = 770 feet.]

The portion of the section marked C indicates the general dip of the beds south of the fault.

In the northernmost quarry, the beds dip  $20^\circ$  southwards, the general strike being E.  $7^\circ$  N. These beds have been folded over

by a thrust coming from the south, so that in the southernmost quarry they are seen forming the southern limb of the fold and still dipping southwards, but at a high angle (about  $70^{\circ}$ ) and with a strike running E.  $13^{\circ}$  S. In the uppermost beds of the northern quarry, and also in the middle quarry (fig. 3), the actual folding of the rocks can be seen.

Fig. 3.—Quarry at the eastern end of Worle Hill, in which the overfolded *Seminula-Beds* are seen.



S. H. Reynolds photogr.

The axis of the fold runs almost due west for about two-thirds of a mile, and in Hatley Rocks the overfolding of the beds is well seen; beyond this point, however, the axis turns south-westward, and the fold dies out against the fault, probably in the neighbourhood of St. Kew's Steps. At St. Kew's Steps the highest beds seen, which represent the top of  $S_1$ , dip at about  $20^{\circ}$  a little east of south.

Parts of  $S_2$  are exposed along the top of the escarpment, between the eastern end of the ridge and Hatley Rocks; and the top of  $S_1$  is well seen in a small quarry, above the road, 1100 yards east of Kewstoke Parish-Church. A lower part of  $S_1$  is exposed in another small quarry, 600 yards farther west.

### (3) The Faunal Sequence.

[Throughout the palæontological part of this paper I have followed exactly the system of nomenclature employed by Dr. Arthur Vaughan in his paper on 'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area' Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 181 *et seqq.* Forms found in the Weston District, which are not recorded in that paper, are referred to in the notes on p. 557.]

#### Syringothyris-Zone.

No brachiopods or corals have been recorded from the 'laminosadolomites' or from the 'Caninia-Oolite.' The following lists, therefore, apply only to the succeeding 450 feet of the zone.

##### Coral-fauna:—

- Caninia cylindrica*.
- Zaphrentis* aff. *cornucopiæ*.
- Cyathophyllum*  $\phi$ : occurs throughout: abundant in the upper part.
- Lithostrotion Martini*: rare; recorded at the top only.
- Michelinia megastoma*.
- Syringopora* cf. *distans*.
- Syringopora* cf. *reticulata*.

##### Brachiopod-fauna:—

- Dielasma* sp.
- Seminula* aff. *ficoidea*: occasional in the upper beds.
- Seminula ambigua* } prominent in the upper beds.
- Athyris* cf. *expansa* }
- Reticularia* aff. *lineata*.
- Spirifer* cf. *bisulcatus*.
- Spirifer* cf. *striatus*.
- Syringothyris cuspidata*: occurs persistently; abundant in the middle of the series.
- Syringothyris* aff. *laminosa*.
- Leptaena* sp.
- Orthotetes* aff. *crenistris* (mut. C): occurs throughout; abundant at certain levels.
- Rhipidomella* aff. *Michelini*.
- Derbya* sp.
- Chonetes papilionacea*: abundant at numerous levels throughout.
- Chonetes* cf. *comoides*: abundant at numerous levels in the lower part.
- Productus semireticulatus*, mut. (cf. *Pr. concinnus*): occurs persistently.
- Productus* aff. *Cora* (mut. C).
- Productus*  $\theta$ .
- Productus*, sp. nov. (See p. 557.)

The bryozoan '*Chaetetes*' *tumidus* occurs in the upper part of the zone, as it does in neighbouring areas.



## Seminula-Zone.

## Coral-fauna :—

- Cyathophyllum* sp. (cf. *C. φ*) : in the lower part of  $S_1$ .  
*Caninia cylindrica* (?) : in  $S_1$ .  
*Lithostrotion Martini* : very abundant throughout.  
*Lithostrotion basaltiforme*, var. *bristolense* : abundant at a certain level in  $S_2$ .  
*Lithostrotion* cf. *Portlocki* : occurs in  $S_2$ .  
 ' *Clisiophyllum* ' (*Carcinophyllum*)  $\theta$  : occurs in  $S_2$ .  
 ' *Clisiophyllum* ' (*Carcinophyllum*) sp. : common at the base of  $S_1$ .  
*Syringopora* cf. *reticulata* : occurs in  $S_1$ .  
*Syringopora* cf. *distans* : abundant at the base of  $S_1$ .  
*Syringopora* cf. *geniculata*.  
*Syringopora* cf. *ramulosa*.

## Brachiopod-fauna :—

- Seminula ficoidea* : abundant throughout.  
*Athyris* cf. *expansa* : persistent throughout  $S_1$ , and common at the top of that subzone.  
*Athyris* cf. *planosulcata* : not uncommon in  $S_1$ .  
 ' *Athyris* ' cf. *glabristria* : abundant at the base of  $S_1$ .  
*Reticularia* sp.  
*Spirifer* cf. *furcatus* : abundant at the base of  $S_1$ .  
*Cyrtina carbonaria* : abundant near the base of  $S_2$ .  
*Cammarophoria isorhyncha* : abundant at the base of  $S_1$ .  
*Orthotetes* aff. *crenistris* : comparatively rare.  
*Chonetes papilionacea* : abundant at numerous levels throughout.  
*Productus* aff. *Cora* [mut. C] is abundant at the base of the zone, and ranges to the top of  $S_1$ .  
*Productus* aff. *Cora* [cf. mut.  $S_2$ ] : occurs in  $S_2$ .  
*Productus* aff. *hemisphericus* : two distinct mutations are abundant, one in  $S_1$ , the other in  $S_2$ .  
*Productus*  $\theta$  : recorded at various levels in  $S_1$ .  
*Productus punctatus* : abundant at the base of  $S_1$ .  
*Productus semireticulatus*, mut. [cf. *Pr. concinnus*] : occurs up to the top of  $S_1$ .

The faunal characters of the *Seminula*-Zone, as displayed in the Weston-Worle ridge, may be summarized as follows. The *semi-reticulatus* subzone ( $S_1$ ) is well-developed, and clearly exhibits a faunal overlap between the *Syringothyris* and *Seminula*-Zones. A remarkably-rich and interesting fauna is found at the base of  $S_1$ . The *Cora*-subzone ( $S_2$ ), so far as it is represented, exhibits a fairly-normal development.

## Notes on New and Interesting Forms.

*Leptæna* sp. has been found in the upper part of C. The highest record of *Leptæna* in neighbouring areas is at Horizon  $\gamma$ .

A new species of the *punctatus*-group of *Producti* has been recorded at the same level. This form has been found<sup>1</sup> in abundance in  $S_1$  in the Carboniferous Limestone of South-West Gower

<sup>1</sup> A. Vaughan, 'Notes on the Brachiopods & Corals, collected by Dr. Brendon Gubbin, from the Carboniferous Limestone of South-West Gower, & the Zones which they indicate' Proc. Bristol Nat. Soc. ser. 4, vol. i. pt. i, 1905 (issued for 1904) p. 55.

(South Wales); and I have recently recorded it at the base of  $S_1$  at Cheddar.

*Athyris* cf. *expansa* (Phill.) 'Geology of Yorkshire' vol. ii (1836) p. 220 & pl. x, fig. 18, occurs persistently throughout  $C_2$  and  $S_1$ .

'*Athyris*' cf. *glabristria* (compare Phill. *op. cit.* p. 220 & pl. x, fig. 19), *Spirifer* cf. *furcatus*, M'Coy, 'Syn. Carb. Limest. Foss. Ireland' (1844) p. 131 & pl. xxii, fig. 12, and *Camarophoria isorhyncha* (M'Coy) *op. cit.* p. 154 & pl. xviii, fig. 8, occur abundantly at the base of  $S_1$ . *Productus punctatus*, Martin, and '*Clisiophyllum*' (*Carcinophyllum*) sp. are very common at the same level.

*Cyrtina carbonaria* (M'Coy) 'Brit. Pal. Foss.' (1855) p. 442 & pl. iii D, figs. 12-18, is abundant near the base of  $S_2$ .

*Derbya* sp. has been obtained from  $C_2$ . I have recently found the same form in  $C_2$  in the Mendips.

### III. THE WOODSPRING RIDGE (MIDDLE HOPE).

This ridge of Carboniferous Limestone, 2 miles in length, lies 2 miles north of, and runs almost parallel to, the Weston-Worle ridge. The average dip of the beds is about  $30^\circ$  southwards, and the general strike is W., a few degrees S.

The sequence represented here extends from the upper part of the *resupinata*-subzone [ $Z_2$ ] to the '*Caninia*-Oolite' in the *Syringothyris*-Zone. Special interest attaches to this development, owing to the occurrence of contemporaneous igneous rocks<sup>1</sup> at Horizon  $\gamma$ .

The complete sequence is displayed on the coast at the eastern end of the ridge, where it consists of a very fossiliferous development of  $Z_2$  and  $\gamma$ , with volcanic ash at the top; succeeded by an excellent development of the '*laminosa*-dolomites' and the '*Caninia*-Oolite.' The combined thickness of the '*laminosa*-dolomites' and '*Caninia*-Oolite' lies between 200 and 250 feet. The upper part of  $Z_2$ , including Horizon  $\gamma$ , is finely displayed all along the coastline on the north side of the ridge. Three other exposures of the igneous rocks occur, the repetition of these exposures being due to two small dip-faults, running almost at right-angles to the coastline. On the south side of the ridge, at the western end, the top of the '*laminosa*-dolomites' and the fossiliferous sub-Oolite beds are well exposed.

#### The Faunal Sequence.

**Zaphrentis-Zone** (including the upper part of  $Z_2$  and Horizon  $\gamma$ ).

Coral-fauna:—

*Zaphrentis* aff. *Phillipsi*.  
*Zaphrentis* aff. *cornucopiæ*.  
*Caninia cylindrica*.

*Amplexus* cf. *coralloides*.  
*Syringopora*  $\theta$ .  
*Michelinia favosa*.

<sup>1</sup> For a detailed description of the igneous rocks, see Sir A. Geikie & A. Strahan, 'Summary of Progress of the Geological Survey for 1898' pp. 104-11; and C. Lloyd-Morgan & S. H. Reynolds, 'The Igneous Rocks associated with the Carboniferous Limestone of the Bristol District' Quart. Journ. Geol. Soc. vol. lx (1904) p. 137. An excellent map of the Woodspring Ridge accompanies the latter paper.

## Brachiopod-fauna :—

<i>Chiothyris glabristria.</i>	<i>Orthotetes</i> aff. <i>crenistria.</i>
<i>Spirifer</i> cf. <i>cinctus.</i>	<i>Rhipidomella</i> aff. <i>Michelini.</i>
<i>Spirifer</i> aff. <i>clathratus</i> , and var.	<i>Schizophoria resupinata.</i>
<i>Reticularia</i> aff. <i>lineata.</i>	<i>Chonetes</i> cf. <i>hardrensis.</i>
<i>Syringothyris cuspidata.</i>	<i>Chonetes papilionacea.</i>
<i>Syringothyris</i> aff. <i>laminosa.</i>	<i>Productus pustulosus.</i>
<i>Leptæna analoga.</i>	<i>Productus</i> aff. <i>semireticulatus.</i>

In the upper part of  $Z_2$ , the abundance of *Zaphrentis* aff. *cornuopice* and *Syringopora*  $\theta$  is very characteristic. *Amplexus* and *Michelinia* are very common.

Horizon  $\gamma$  is clearly defined by the extreme abundance of *Caninia cylindrica* in association with *Zaphrentis* spp.

**Syringothyris-Zone** (*laminosa*-subzone).

## Brachiopod-fauna :—

<i>Syringothyris cuspidata.</i>	<i>Chonetes</i> cf. <i>comoides.</i>
<i>Syringothyris</i> aff. <i>laminosa.</i>	<i>Chonetes papilionacea.</i>
<i>Orthotetes</i> aff. <i>crenistria.</i>	

The basal beds of the 'Caninia-Oolite' contain abundantly *Chonetes* and *Orthotetes*.

## IV. COMPARISON WITH NEIGHBOURING AREAS.

## (1) The Weston-Worle Ridge.

Some interesting conclusions are arrived at, by comparing the development of the *Syringothyris*-Zone in this area with the equivalent part of the sequence in (1) The Clevedon district<sup>1</sup>; and (2) the Burrington section.<sup>2</sup> Clevedon lies at the western end of the Clifton-to-Clevedon ridge, about 8 miles north-east, slightly north, of Weston-super-Mare, and its immediate neighbourhood is the nearest part of the Bristol area of which we have a complete knowledge. Burrington Combe lies about  $9\frac{1}{2}$  miles east  $10^\circ$  south of Weston, and the development here may be regarded as typical of the Western Mendips.

The occurrence of representatives of the '*laminosa*-dolomites' and '*Caninia*-Oolite' in  $C_1$  in the Weston area constitutes a distinct link with the Clevedon district and, at the same time, a variation from the Burrington type. In the upper part of the zone, however, the thick series of oolitic limestones, containing a typical *Syringothyris*-fauna, indicates the predominance of a Mendip facies; for this development is exactly paralleled in the Burrington section by Horizon  $\delta$  and the greater part of the main *Syringothyris*-Zone, while differing considerably from the equivalent part of the Clevedon sequence.

<sup>1</sup> For an account of the Carboniferous Limestone of the Clevedon district, see A. Vaughan, Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 225-28.

<sup>2</sup> For an account of the Burrington section, see T. F. Sibby, 'The Carboniferous Limestone of Burrington Combe' Proc. Bristol Nat. Soc. ser. 4, vol. i, pt. i, 1905 (issued for 1904) pp. 14-41.

The Weston-Worle ridge displays, then, a more or less intermediate type of development in the *Syringothyris*-Zone, with a Mendip facies predominating to some extent. Future work in the Western Mendips will doubtless furnish many new facts which may throw light on this question.

The *Seminula*-Zone is rather incompletely displayed in this area; but, in so far as it is seen, it presents an extremely-interesting development. Until quite recently, no parallel development of S had been found in the Mendips, for the Burrington section shows but a poor exposure of this part of the sequence, and gives a very inaccurate impression of the characters of the *Seminula*-Zone in the Western Mendips.

Recently, however, in the course of my present work in the Mendips, I have found the same interesting development of S elsewhere. At Cheddar, on the south side of the Mendips, the *Seminula*-Zone is finely displayed in the Gorge, and shows a very striking agreement with the Weston district. This applies especially to  $S_1$ :  $S_2$  is poorly displayed in the Weston-Worle ridge, and at Cheddar it is by no means so well exposed as  $S_1$ ; in both localities, however, it seems to have a normal character.

At Weston-super-Mare, the Milton-Road Quarries have yielded a very rich fauna. *Lithostrotion Martini*, *Syringopora* cf. *distans*, 'Athyris' cf. *glabristria*, *Spirifer* cf. *furcatus*, and *Camarophoria isorhyncha* are abundant. *Productus punctatus* and 'Clisiophyllum' (*Carcinophyllum*) sp. are very common, and *Athyris* cf. *planosulcata* is not infrequent. The base of the *Seminula*-Zone in the Cheddar section contains precisely the same fauna, with one apparent exception, namely, *Productus punctatus*. In both localities this fauna is restricted to a very small vertical thickness of rocks, and it undoubtedly constitutes an important horizon.

This forms the most prominent point of agreement between  $S_1$  at Weston and at Cheddar; but, in addition, the general similarity is complete. For example, the well-marked faunal level at the top of  $S_1$ , showing an association of *Productus semireticulatus* mut. (cf. *Pr. concinnus*), *Productus*  $\theta$ , *Pr.* aff. *hemisphericus*, *Athyris* cf. *expansa*, *A.* aff. *planosulcata*, *Lithostrotion Martini*, and *Caninia cylindrica* (mut.  $S_1$ ), which is so finely displayed at Cheddar, is well represented in the Weston-Worle ridge.

## (2) The Woodspring Ridge.

The characters, both palæontological and lithological, of the sequence displayed here are exactly similar to those of the equivalent part of the Clevedon development.

## V. SUMMARY.

(1) The Carboniferous Limestone of the Weston-Worle ridge includes the greater part of the *Syringothyris*-Zone [C], extending from the 'laminosa-dolomites' to the base of the *Seminula*-Zone, and a great part of the *Seminula*-Zone [S].

(2) There are two important structural features of this ridge :—  
 (a) A reversed fault, running the whole length of the ridge, which has thrown *Syringothyris*-Beds, on the south, against *Seminula*-Beds, on the north; and (b) A large overfold of the *Seminula*-Beds on the north side of this fault.

(3) On the south of the fault there is a sequence from  $C_1$  to  $S_2$ ; on the north S only is represented.

(4) The lower part of C, consisting of the 'laminosa-dolomites' and 'Caninia-Oolite,' and indicating, therefore, the prevalence of shallow-water conditions, resembles the equivalent part of the Clevedon sequence (Bristol area).

(5) The upper part of C, consisting of a thick series of fossiliferous limestones, closely resembles the corresponding part of the Burrington section, and indicates, therefore, the predominance of a Mendip facies.

(6) The *semireticulatus*-subzone [ $S_1$ ] is well developed. There is a very rich and important faunal level at the base. Altogether, the characters of this subzone are in striking agreement with those of the same subzone at Cheddar, in the Mendips.

(7) The *Cora*-subzone [ $S_2$ ] is very incompletely displayed; but, so far as can be determined, it is normally developed.

(8) The Woodspring ridge shows a sequence from the Upper *Zaphrentis*-Zone [ $Z_2$ ] to the top of  $C_1$ . The whole of this series is exactly similar to the equivalent part of the Clevedon sequence, that is, the higher part of  $Z_2$  is very fossiliferous, and Horizon  $\gamma$  (characterized by the association of *Zaphrentis* spp. with very abundant *Caninia cylindrica*) is clearly defined; while  $C_1$  consists of a fine development of the 'laminosa-dolomites' and 'Caninia-Oolite.'

(9) In the Woodspring ridge the contemporaneous igneous rocks occur at Horizon  $\gamma$ . In the Weston-Worle ridge, however, the igneous rocks occur just above the 'Caninia-Oolite,' and about 450 feet below the top of C. It is evident, therefore, that there were two periods of volcanic activity in this district, one of which occurred at the close of *Zaphrentis*-time, while the other occurred comparatively early in *Syringothyris*-time.

#### DISCUSSION.

The CHAIRMAN (Mr. R. S. Herries) said that he was glad to welcome a new author who was taking up the interesting and, so to speak, fashionable line of zoning the Carboniferous rocks.

Dr. WHEELTON HIND congratulated the Author on the accomplishment of a very successful piece of work on the Weston-Worle Carboniferous ridge. The speaker had had the advantage of being conducted over the ground by the Author, and he was of opinion that the latter's conclusions were correct. There was no doubt as to which divisions of the Avon section, and their equivalents in the Burrington Gorge north of the Mendips, the beds exposed near Weston belonged. The palæontological study of the rocks made

this definite and certain, thanks to Dr. Vaughan's masterly study of the Avon and other sections round Bristol.

The Author had had the treble advantage of working in an area where the stratigraphical sequence was obvious, where there had been very little movement, and where the fossils occurred in certain definite zones; and the speaker thought it might be said that, so far as the Mendip, Bristol, and South-Wales area of Lower Carboniferous rocks was concerned, they were now zoned by the corals and brachiopods. Unfortunately, other families of fossils were very rare there. The speaker had stated, on more than one occasion, that he had been unable to adopt any method for zoning the Lower Carboniferous rocks of the Midlands, and he was of opinion that the same hard-and-fast lines did not obtain there as near Bristol. For example, *Zaphrentis* did occur above a Viséan fauna, and many other apparent inconsistencies existed with the Bristol life-zones. But, a solution having been obtained for one district, he was hopeful that something would be discovered which would enable them to unravel the riddle of the Midlands.

With regard to the fauna of the Mendip and Bristol Carboniferous area, the speaker was astonished at the limited number of species. Many brachiopods, common in the Midlands, had not been found. Lamellibranchs and gasteropods were extremely rare, and cephalopoda were almost entirely unrepresented. On the other hand, the speaker had never met, in the Midlands, with *Camarophoria isorhyncha* and 'Athyris' cf. *glabristria*, so common at the Milton-Road quarries. He had also failed to meet in the Midlands with *Seminula ficoidea*, which was so characteristic of certain zones in the Avon section.

Assuming that the Carboniferous Limestone of Belgium extended by way of the Mendips and South Wales to the South of Ireland, the contrast between the richness of the fauna, of Belgium on the east and Ireland on the west, and that of the Bristol area was marked, and pointed to distinct bathymetrical conditions.

Mr. C. B. WEDD stated that, in mapping the Matlock district of Derbyshire for the Geological Survey, he was attempting a subdivision of the Carboniferous Limestone on the lines employed by Dr. Vaughan and the Author, but was relying chiefly on the corals. Owing to the anticlinal form of the limestone-mass, it had not been possible to examine a sufficiently-great thickness to test Dr. Vaughan's subdivisions completely; but, so far as comparison could be made between the Matlock and Bristol districts, he found points of agreement underlying a certain amount of discrepancy. The *Dibunophyllum*-type of coral was characteristic of a high horizon in the Matlock as in the Bristol district, and various forms of *Lithostrotion* also agreed fairly well in their distribution. So far, he had reason to believe that in the Matlock area certain corals characterized certain horizons, and had a limited vertical range.

The limestone described in the present paper appeared to belong to a lower horizon than any that he had yet examined in Derbyshire, and consequently the contemporaneous igneous rocks associated with

it were lower in the sequence than the interstratified toadstones of the eastern part of the Derbyshire limestone.

Mr. E. DIXON welcomed this, the first instance in which the zones, established by Dr. Vaughan for the Carboniferous Limestone of the Bristol area, had been used to unravel the structure of another district. The particular district selected, although not investigated personally by the speaker, was of considerable interest to him, because the structures revealed by the mapping of the zones were similar to the structures recognized by the same means by the Geological Survey in South Pembrokeshire, 80 miles to the west. There Dr. Vaughan had convinced him, during the course of a short visit, that the zones are developed, with but trifling exceptions, with the same faunas as at Bristol. The results of the application of the zoning to the Midland area would, therefore, be awaited with great interest.

Mr. STRAHAN suggested that the district offered an opportunity of comparing the values of rock-beds and fossil faunas as tests of contemporaneity. The Woodspring and Worle ridges of limestone had been recognized from the first as repetitions of the same set of strata, by folding or overthrusting concealed beneath the alluvium. In each there occurred a single volcanic series at approximately the same horizon, while a similar series was known at Uphill, on or about the same horizon. Obviously, it might be inferred that there was one volcanic series repeated with the rest of the limestone-series in all three localities. The Author, however, showed that the volcanic rocks did not occupy the same faunal horizon at Woodspring as at Worle, and inferred that there had been two outbursts, although in neither locality had he been able to detect the presence of more than one set of volcanic rocks.

If there was only one outburst, the volcanic material must have been spread simultaneously over the whole region. In that case the faunal development could not have been contemporaneous, but must have suffered what had been conveniently called 'relative acceleration' in one or the other locality. If, on the other hand, there were two outbursts, the faunal development may have been strictly contemporaneous. The evidence, although meagre and of a negative character, appeared rather to favour the former hypothesis.

He wished, in conclusion, to testify to the value of the faunal work accomplished by Dr. Vaughan. The zones established by him had been found to hold good in South Wales, wherever opportunity had arisen of testing them.

Mr. DIXON (by permission of the Chairman) read an extract from a letter which he had received from Dr. Vaughan, in explanation of a difficulty raised in the discussion by the previous speaker.

26. OBSERVATIONS on some of the LOXONEMATIDÆ, with DESCRIPTIONS of Two NEW SPECIES. By Miss JANE DONALD. (Communicated by Prof. THEODORE GROOM, M.A., D.Sc., F.G.S. Read March 8th, 1905.)

[PLATE XXXVII *pars*.]

THE genus *Loxonema* was founded by Phillips in 1841, and was thus described by him :—

‘Spiral, turriculated; whorls convex, their upper edges adpressed against the next above; without spiral band; mouth oblong, attenuated above, effused below, with a sigmoidal edge to the right lip; no umbilicus (?); surface covered by longitudinal threads or ridges, generally arched.’

He further states that these observations are merely provisional, until the form of the aperture is more perfectly known.<sup>1</sup> In noting the number of species, he writes that most of them are probably

‘varieties of three or four types having *L. sinuosa* for one extremity and *L. Hennahii* for the other; a second related to *L. tumida* and *L. lincta*; a third to *L. rugifera*.’ [*Loc. cit.*]

Later researches show that this description is correct for the group of shells having *Loxonema sinuosum* for the type, and the generic name must be restricted to them. The essential characteristics are the possession of whorls adpressed at the suture and the presence of strongly-sigmoidal lines of growth. Shells having more convex whorls, or less sigmoidal lines of growth, must be placed elsewhere. Prof. Koken and other palæontologists have created several new genera for some of these latter. The type, *Loxonema sinuosum*, is the first species described by Phillips: it is a Devonian form from South Petherwyn, which he identifies with *Terebra* (?) *sinuosa*, Sow.<sup>2</sup> from the Aymestry Limestone. They are probably distinct species, although Mr. Whidborne<sup>3</sup> thinks them correctly identified. The striæ on the Devonian form are coarser and more raised, as Phillips remarks. Both, however, agree in having the characteristic features of the genus.

The two new species which I am about to describe resemble the type in form, and in the sinuosity of the lines of growth; but the whorls, instead of being smooth, are ornamented by spiral striæ, two of which frequently stand out and impart to the shell a banded appearance. The specimens that I have seen are not well enough preserved to show whether the two lines originally were really stronger, or whether this appearance is merely an accident resulting from the manner of preservation. This spiral ornamentation can hardly be considered of sufficient importance, taken alone, to cause their separation from the genus *Loxonema*; but, should the discovery of

<sup>1</sup> ‘Pal. Foss. Devon, &c.’ p. 98.

<sup>2</sup> In Murchison’s ‘Silurian System’ 1839, p. 619 & pl. viii, fig. 15.

<sup>3</sup> ‘The Devonian Fauna of the South of England’ pt. iii, Monogr. Pal. Soc. vol. xlv (1890-91) p. 176.



better specimens show further distinctive features, such as to justify their forming a new subgenus, I would suggest the name of *Rhabdostrophæ*. Both these species are of Silurian age.

Several forms possessing spirally striated whorls have been described among the Loxonematidæ, but they all differ from the species under discussion by having the lines of growth much less sigmoidal. Among them may be mentioned the Devonian *Loxonema reticulatum*, Phill.,<sup>1</sup> and numerous Triassic shells, some of which have been referred to new genera. One of these new genera, namely, *Heterocosmia*, Koken,<sup>2</sup> differs still further, in having more convex whorls which are not adpressed at the suture.

Hitherto but two British species of *Loxonema* have been described of Silurian age, namely, *L. sinuosum*, Sow., and *L. elegans*, M'Coy.<sup>3</sup> The former is a good species; the only specimen of the latter, however, is too imperfect to make anything of. It is from the Lower Ludlow Beds.

I desire here to express my gratitude to Prof. T. McKenny Hughes, F.R.S., for the loan of specimens, and to Mr. E. T. Newton, F.R.S., Mr. H. A. Allen, and Mr. R. B. Newton, for their kindness in affording me facilities in studying fossils under their care. My sincere thanks are also due to Mr. C. D. Sherborn and Mr. J. G. Goodechild for assistance in looking up references.

#### Family LOXONEMATIDÆ, Koken.

##### Genus LOXONEMA, Phill.

LOXONEMA GRINDRODII, sp. nov. (Pl. XXXVII, fig. 1.)

Diagnosis.—Shell elongated, turriculated, composed of more than four whorls. Whorls increasing gradually, adpressed at the suture, convex below. Ornamented by fine spiral lines, two of which are sometimes stronger than the others, and give the appearance of a band situated rather below the middle of the whorl. Lines of growth sigmoidal, numerous fine lines being intercalated between stronger ones, and the greatest sinuosity occurring slightly above the middle of the whorl or else being sub-median. Aperture sub-ovoid.

Remarks and Resemblances.—The best-preserved specimen of this species is in the Museum of Practical Geology, Jermyn Street. There are three examples in Prof. Groom's collection, which possibly belong to it, but the surface of none of them is well preserved, the biggest alone showing some traces of spiral striæ and lines of growth. The spire seems more slender; this may, however, be partly accounted for by the manner of preservation, as all are external

<sup>1</sup> 'Pal. Foss. Devon, &c.' 1841, p. 139 & pl. lx, fig. 187\*.

<sup>2</sup> Neues Jahrb. vol. ii (1892) p. 30, footnote.

<sup>3</sup> 'Brit. Palæoz. Foss.' 1852, p. 302 & pl. i K, fig. 34.

moulds. In general form this species resembles *Loxonema intumescens*,<sup>1</sup> Lindström, but there is no spiral ornamentation in that species. It is much less slender than *L. (?) fasciatum*,<sup>2</sup> Lindström, which possesses an indistinct band, having however no bordering lines nor accessory spiral striæ.

**Dimensions.**—The length of the specimen in the Museum of Practical Geology, having the apex broken and consisting of about four whorls, is 34·5 millimetres; the width = 17 mm. The biggest of Prof. Groom's examples is imperfect, both at the apex and at the base: it consists of about five whorls in a length of 28·5 mm.; the penultimate whorl is 10 mm. in width.

**Locality and Horizon.**—The specimen in the Museum of Practical Geology is from the Aymestry Limestone, near Ledbury. Prof. Groom's specimens are from the Lower Ludlow, Aymestry Limestone included (63), at Llangadock.

*LOXONEMA PSEUDOFASCIATUM*, sp. nov. (Pl. XXXVII, fig. 2.)

**Diagnosis.**—Shell elongated, turriculated, composed of numerous whorls. Whorls increasing gradually, adpressed at the suture, very slightly convex below. Ornamented by fine spiral lines, two of which are sometimes stronger than the others, and produce the appearance of a band situated above the middle of the whorl. Lines of growth sigmoidal, numerous, stronger lines being intercalated at intervals among the fine lines, and the greatest sinuosity occurring above the middle of the whorl. Aperture unknown.

**Remarks and Resemblances.**—I have met with only one specimen, which is in the Sedgwick Museum at Cambridge. It is referred to as *Murchisonia* by J. W. Salter in his 'Catal. Cambr. & Silur. Foss. Cambridge Museum' 1873, p. 155, sp. 3, b 809, and is marked *Hormotoma*. The structure above described shows that it is distinct from that genus, and more nearly allied to *Loxonema*. It greatly resembles *L. Grindrodii*, but the whorls are higher, more flattened, and the greatest sinuosity of the lines of growth is situated higher up the whorl.

**Dimensions.**—The shell is imperfect, only three whorls being preserved, which have a length of 46 millimetres; the greatest width = 24 mm.

**Locality and Horizon.**—Wenlock Limestone, Dudley.

#### EXPLANATION OF PLATE XXXVII *pars*.

Fig. 1. *Loxonema Grindrodii*, sp. nov.  $\times 1\frac{1}{2}$ . Aymestry Limestone, near Ledbury. Museum of Practical Geology, Jernyn Street, London.

2. *Loxonema pseudofasciatum*, sp. nov. Nat. size. Wenlock Limestone, Dudley. Sedgwick Museum, Cambridge.

<sup>1</sup> 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vet.-Akad. Handl. vol. xix (1881-84) No. 6, p. 143 & pl. xv, fig. 6..

<sup>2</sup> *Ibid.* p. 144, pl. xv, fig. 11 & pl. xx, fig. 7.

27. *On some GASTEROPODA from the SILURIAN ROCKS of LLANGADOCK (CAERMARTHENSHIRE).* By Miss JANE DONALD. (Communicated by Prof. THEODORE GROOM, M.A., D.Sc., F.G.S. Read March 8th, 1905.)

[PLATE XXXVII pars.]

PROF. GROOM has sent me some pieces of rock of Silurian age, from Llangadock, containing a number of gasteropoda. These fossils occur almost entirely in the state of internal and external moulds. The former rarely show much structure, but by pressing wax into the latter the original form and ornamentation of the shells are frequently reproduced, in such a manner as to give a tolerably-good idea of the original. By this means I have been able to make out ten distinct forms, which are referable to seven different genera, but only seven are sufficiently well preserved to be specifically determined with any degree of certainty. They may be enumerated thus:—

*Plethospira* [*Ulrichospira*] *similis*,  
sp. nov.  
*Bembexia* (?) *Groomii*, sp. nov.  
*Bembexia* (?) sp. nov.  
*Bembexia* (?) *Lloydii* (Sow.).  
*Murchisonia* [*Goniostrophæ*] *Cambria*,  
sp. nov.

*Murchisonia* [*Cyrtostrophæ*] *tor-*  
*quata* (?) M'Coy.  
*Loxonema sinuosum* (?) Sow.  
*Loxonema Grindrodii* (?) Don.  
*Gyronema Octavia* (d'Orb.).  
*Polytropina globosa* (Schloth.)

Two small external moulds from the Upper Ludlow Beds, of which the wax-impressions bear some resemblance to *Cyrtostrophæ torquata* (M'Coy) are too imperfect for certain identification. The same may be said of the much-worn internal mould from the Wenlock Beds, which possibly represents *Loxonema sinuosum* (Sow.). Besides these doubtful ones, there are three other species from Llangadock which have been previously described by other palæontologists, namely, *Bembexia* (?) *Lloydii* (Sow.), *Gyronema Octavia* (d'Orb.), and *Polytropina globosa* (Schloth.). They all have a wide range, and cannot be considered characteristic of any particular horizon. *Gyronema Octavia* (d'Orb.) is by far the most numerous form, there being but few individuals of any of the other species.

The numerals in parentheses prefixed to the horizons of the several species refer to the specimens in Prof. Groom's collection, and to localities on the map with which he hopes to illustrate a forthcoming paper.

I must here offer hearty thanks for the facilities afforded me in studying specimens in the Museum of Practical Geology by Mr. E. T. Newton, F.R.S., and Mr. H. A. Allen, and in the Natural History Museum by Mr. R. B. Newton. I am also greatly indebted to Mr. C. D. Sherborn for assistance in looking up references.

## Family PLEUROTOMARIIDÆ, d'Orb.

The Palæozoic forms referred to *Pleurotomaria* require revision, for few, if any, can strictly be placed in that genus. Many new genera and subgenera have been created from '*Pleurotomaria*' by different palæontologists, both in Europe and in America, but they hardly meet all the needs of the case. Hence, it is often difficult to decide to which of the existing divisions a species should be referred; nevertheless, I feel that caution is necessary before suggesting new ones, until I have been able to review the whole series of forms.

In describing the shells before me at present this difficulty is evident. The first species mentioned above (p. 567) comes nearest to examples placed in the genus *Plethospira*, Ulrich<sup>1</sup>; not, however, to the type, *Pl. cassina* (Whitf.), but to *Pl. Semele* (Hall), as represented by Ulrich in pl. lxx, figs. 8-10 (*op. cit.*). This species and also *Pl. striata*, Ulrich (pl. lxx, fig. 7), have less convex whorls than the type, and *Pl. Semele* is moreover ornamented by two keels like the species under discussion, whereas the type has perfectly-smooth whorls. Ulrich remarks (*op. cit.* p. 1009) that

'these two species [*Pl. striata* and *Pl. Semele*] are perhaps not very good examples of *Plethospira*, still, it would be difficult to pick out any important differences.'

It would, perhaps, be advisable to place them, as well as the Welsh species, in a separate group, for which I would suggest the name *Ulrichospira*.

The other three species, *Pleurotomaria Lloydii*, Sow., *Pl. Groomii*, sp. nov., and a fragment hardly sufficient to identify, most nearly resemble shells referred to *Bembexia*, Ehlert.<sup>2</sup> This genus is distinguished from *Ptychomphalus*, Agass., by its more turriculated form, more angular whorls, and by having the band situated on the summit of the angle and at a little distance from, instead of immediately above, the suture. Ehlert further distinguishes it by stating that the columellar border is thickened and the band wide.

The three species here described are turriculated, and the band is situated on the angle of the whorls, a little distance above the suture. They none of them show the columellar border, and the band is of moderate width; it could hardly be called wide in any of them, except perhaps in *Bembexia* (?) *Groomii*, where it is tolerably wide in proportion to the shell.

Ulrich refers *Pleurotomaria* (*Bembexia*?) *Lloydii* (*op. cit.* p. 1012) to his genus *Seelya*, but it is distinguished from the members of that genus by possessing a slit in the outer lip, by more oblique lines of growth, and by the band being narrower. The lines of growth appear to be more oblique than those of the other two

<sup>1</sup> Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 958.

<sup>2</sup> 'Descriptions de quelques Espèces dévoniennes du Département de la Mayenne' p. 24 (Extrait du Bull. Soc. d'Études Scientifiques d'Angers, 1887).

species here described, and also than the type of *Bembexia*; therefore *Pleurotomaria Lloydii* may eventually have to be placed in a new and separate genus. I shall be able to decide this point better, when I have had time to study the numerous specimens from other localities.

### Genus PLETHOSPIRA, Ulrich.

#### Subgenus ULRICHOSPIRA, nov.

**Diagnosis.**—Shell subconical; whorls about five, moderately convex, subangular at the periphery where the band is situated. Band concave, bounded on each side by a strong keel. Ornamentation sometimes consisting of accessory keels.

**Type.**—*Ulrichospira similis*, sp. nov.

**Remarks.**—This subgenus differs from *Plethospira* in having less convex whorls, and in sometimes being ornamented by keels in addition to those bounding the band.

#### ULRICHOSPIRA SIMILIS, sp. nov. (Pl. XXXVII, fig. 3.)

**Diagnosis.**—Shell small, subconical, composed of more than three whorls. Whorls increasing at a moderate rate, somewhat convex, but with a slight angularity at the periphery where the band is placed. Band submedian, rather concave, bounded on each side by a prominent keel. Ornamentation consisting of a slight ridge just below the suture, a fainter one between this and the band, and a strong keel below the band, which appears immediately above the suture on the earlier whorls; above this keel is a narrow groove. Lines of growth sharp and distinct, making an acute angle on the upper ridge, then forming a strongly-concave curve in their backward sweep to the band, but slightly curved on the band itself and passing downwards almost vertically; closer together on the base. Aperture unknown.

**Remarks and Resemblances.**—There is but one known specimen of this species. It greatly resembles *Murchisonia pulchra*, M'Coy,<sup>1</sup> but may be distinguished by the band being grooved instead of being prominent in the middle, by the bordering keels being stronger, by the upper ridge being more marked, the lines of growth making more concave curves, and by the presence of a narrow groove above the lower keel. The lines of growth appear to indicate a sinus rather than a slit in the outer lip; consequently this species cannot be regarded as a true *Pleurotomaria*.

**Dimensions.**—Length = 10 millimetres; width = 8 mm.

**Horizon.**—(17) Upper Llandovery.

### BEMBEXIA, Ehlert.

#### BEMBEXIA (?) GROOMII, sp. nov. (Pl. XXXVII, fig. 4.)

**Diagnosis.**—Shell very small, conical, consisting of more than five whorls. Whorls but slightly convex, subangular at the

<sup>1</sup> 'Synopsis of the Silurian Fossils of Ireland' 1846, p. 16 & pl. i, fig. 19.

periphery where the band is situated, somewhat flattened both above and below. Band situated near the middle of the body-whorl, but considerably below the middle on the earlier whorls, concave, and bounded on each side by a strong keel. Ornamentation consisting of four strong threads below the band on the body-whorl, not seen on the earlier whorls; two fine threads on the upper part, one immediately below the suture, and the other midway between it and the band. Lines of growth strong, raised threads occurring on the upper part of the whorl, almost crenulating the uppermost thread, curving obliquely back to the band, not clearly visible on the rest of the surface, apparently curving forward below the band on the penultimate whorl. Aperture unknown.

Remarks and Resemblances.—There are three specimens of this species, one of which is very small. The structure is not well enough preserved to permit of its being referred with certainty to any of the subdivisions of *Pleurotomaria*, but it appears to come nearer to *Bembevia*, Ehlert, than to any other genus. I therefore place it here provisionally. This species somewhat resembles *Pleurotomaria crenulata*, McCoy,<sup>1</sup> but differs in having the base more produced and ornamented by four raised threads. This ornamentation also distinguishes it from *Pl. Hindei*, Lindström,<sup>2</sup> to which it bears a resemblance in form and in the character of the band. It differs from small specimens of *Pleurotomaria Lloydii*, Sow., by not having so many strong raised threads above the band, by the upper thread being almost crenulated, by the form of the lines of growth, and by the band being wider in proportion.

Dimensions.—Length = 4·5 millimetres; width of penultimate whorl = 2·5 mm.; height of body-whorl = 2·5 mm.

Horizon.—(63) Lower Ludlow, Aymestry Limestone included.

*BEMBEXIA* (?) sp. nov. (Pl. XXXVII, fig. 5.)

A fragment of the upper part of a shell is partly embedded in the matrix, and only shows four and a half whorls. The whorls are slightly angular at the periphery, where the band is situated, and flattened above and below. The band is below the middle of the whorls, and is prominent and flat; it is not well enough preserved to show whether it was bordered by keels. The surface is smooth, with the exception of a few obscure lines of growth on the fragment of the upper part of the last whorl, which curve backward to the band.

Remarks and Resemblances.—This species comes near to *Pleurotomaria Holmi*, Lindström,<sup>3</sup> more especially the variety figured in his pl. xix, fig. 17, which is devoid of the ridge below the suture characteristic of the type. It differs, however, in the position of

<sup>1</sup> 'Brit. Palæoz. Foss.' 1852, p. 291 & pl. i K, figs. 45-45 a.

<sup>2</sup> 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vet.-Akad. Handl. vol. xix (1881-84) No. 6, p. 99 & pl. xix, figs. 15-16.

<sup>3</sup> *Ibid.* p. 100 & pl. xix, figs. 17-20.

the band, which is below the middle of the whorl, instead of being submedian. As the specimen is very imperfect, it seems inadvisable to assign to it a specific name, for it might possibly be a worn example of an already described species, such as *Bembexia* (?) *Lloydii*, for instance.

Dimensions.—The length of the fragment consisting of four and a half whorls = 10 millimetres; the width of the penultimate whorl = 6.5 mm.

Horizon.—(90) Wenlock.

#### BEMBEXIA LLOYDII? (Sow.).

A fragment of a shell appears identical with this species.

Dimensions.—The length of the fragment, consisting of about six whorls, is 14 millimetres.

Horizon.—(67a) Upper Ludlow.

Etheridge gives the range of *Pleurotomaria Lloydii* as from the Wenlock Shale to the Upper Ludlow inclusive. '*Murchisonia*' *sulcata*, M'Coy,<sup>1</sup> which is identical with *Pleurotomaria Lloydii*, is recorded from the Lower Llandovery. Lindström records its occurrence in all the Silurian strata of Gothland.

#### Family MURCHISONIIDÆ, Koken.

##### Genus GONIOSTROPHA, Ehlert.

#### GONIOSTROPHA CAMBRIA, sp. nov. (Pl. XXXVII, fig. 6.)

Diagnosis.—Shell very small, slender, turreted, composed of more than ten whorls. Whorls increasing very gradually, angular rather above the middle of the body-whorl, concave above, slightly convex below. Surface smooth, no lines of growth being seen. Band situated on the angle, grooved, and bounded on each side by a strong raised thread. Base convex. Aperture imperfectly known, subovoid.

Remarks and Resemblances.—There is only one specimen of this species, but it is fairly well preserved, the grooved band and contour of the whorls being clearly seen. It resembles *Goniotropha* (?) *elegans* (Sollas),<sup>2</sup> from the Lower Wenlock of Rhymney, but is much smaller, the band is proportionately more widely grooved, the whorl less concave above, and it is also devoid of the keels above and below the suture.

Dimensions.—The single specimen consists of ten whorls, and the apex is broken; if it were intact, there would probably be two or three more whorls. Length = 8 millimetres; width = 2.25 mm.

Horizon.—(63) Lower Ludlow, Aymestry Limestone included.

<sup>1</sup> 'Synopsis of the Silurian Fossils of Ireland' 1846, p. 17 & pl. i, fig. 20.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. lvi (1902) p. 321 & pl. vii, figs. 2-4.

## Subgenus CYRTOSTROPHA, Don.

## CYRTOSTROPHA TORQUATA? (M'Coy).

Two, very imperfect, external moulds possibly belong to this species, but the state of preservation is so bad that it is impossible to be sure.

Dimensions.—The best specimen consists of about six whorls in a length of 8 millimetres; width = 3 mm.

Horizon.—(67*a*) Upper Ludlow.

This species is characteristic, elsewhere in Britain, of the Upper Ludlow. It is not recorded from Gothland.

## Family LOXONEMATIDÆ, Koken.

## Genus LOXONEMA, Phillips.

## LOXONEMA SINUOSUM? (Sow.).

A much-worn internal mould bears a great resemblance to this species, but I can only refer it here with a query, as it is so imperfectly preserved.

Dimensions.—The specimen is embedded in the matrix, and shows only three whorls, which have a length of 14 millimetres.

Horizon.—(99) Wenlock.

Elsewhere in Britain Etheridge recorded it from the Upper Llandovery, Lower Ludlow, and Aymestry Limestone. I have also seen specimens from the Wenlock of Dudley. An example from the Middle Devonian of South Petherwyn is referred to this species by Phillips, and Mr. Whidborne considers that it has been correctly identified.

In Gothland it occurs in the Upper Llandovery and Wenlock, that is, in Lindström's stratum *a*.

## LOXONEMA GRINDRODII(?) Don. (Pl. XXXVII, figs. 7–9.)

There are three specimens of *Loxonema* which have the surface too poorly preserved to permit of their being identified with certainty. The biggest one shows traces of spiral striæ, which, together with its general form, cause it to resemble *L. Grindrodii*, but both it and the other two examples are more slender. This may arise, partly at any rate, from the manner of preservation; or, on the other hand, it may indicate that they belong to a distinct species. It hardly seems advisable to found a new species on specimens so imperfect, therefore I refer them for the present with a query to *L. Grindrodii*.

Dimensions.—The biggest example figured (Pl. XXXVII, fig. 7) consists of portions of five whorls in a length of 28.5 millimetres; the width of the penultimate whorl = 10 mm. The specimen showing the aperture, and having only three whorls preserved, is 18 mm. long, and the penultimate whorl is 7.5 mm. wide. The smallest specimen figured (Pl. XXXVII, fig. 9) is 11.5 mm. in length, and consists of about nine whorls.

Horizon.—(63) Lower Ludlow, Aymestry Limestone included.



## Family TROCHONEMATIDÆ, Ulrich.

Genus GYRONEMA, Ulrich.<sup>1</sup>

Diagnosis.—Whorls ventricose; aperture moderately oblique; umbilicus small. Ornamentation consisting of spiral ridges, two of which often form a more or less distinctly-marked peripheral band, the ridges being most numerous on the base.

Type.—*Gyronema pulchellum*, Ulrich.<sup>2</sup>

Remarks and Resemblances.—This genus was created for the reception of shells intermediate in character between *Trochonema*, Salter, and *Cyclonema*, Hall. The open umbilicus, as well as a vertical peripheral band, connects it with *Trochonema*. It is distinguished from that genus by the more elevated spire, less oblique aperture, and also by the peripheral band not being quite so distinctly marked, and there is frequently a submedian keel on it. The elevated spire causes it to bear some resemblance to *Cyclonema*, but it differs in having an open umbilicus.

## GYRONEMA OCTAVIA (d'Orb.). (Pl. XXXVII, figs. 10–15.)

*Turbo carinatus*, J. de C. Sowerby, 1839, in Murchison's 'Silurian System' p. 612 & pl. v, fig. 28; non *Turbo carinatus*, Sow. 'Mineral Conchology' 1821, pl. ccxi, fig. 3; non *Turbo carinatus*, Höninghaus, 1830, Jahrb. f. Min. Geol. & Petrefkde. p. 230, which is identical with *Helix carinatus*, Sow. 'Min. Conch.' 1812, vol. i, p. 34 & pl. x.

*Turbo Octavia*, A. d'Orbigny, 1850, 'Prodrome de Paléontologie stratigraphique' vol. i, p. 30.

*Cyclonema carinatum*, G. Lindström, 1884, 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vet.-Akad. Handl. vol. xix, No. 6, p. 178 & pl. xviii, figs. 28–30.

Diagnosis.—Shell turbate, acute, having about six whorls. Whorls increasing somewhat rapidly, convex, ornamented by spiral keels. The three or four upper keels are frequently stronger than the others; the grooves between them vary in width, and the third groove generally forms a peripheral band. There are additional keels on the body-whorl, which vary in number on different specimens, and there is always a strong ridge round the umbilicus. The lines of growth cross the keels rather obliquely, and some are so strong as to be almost lamellar. Umbilicus open. Aperture subovate; outer lip thin and sharp; inner lip reflected on the body-whorl, and partly covering the umbilicus.

Remarks and Resemblances.—The type of Sowerby's *Turbo carinatus* is stated to be from the Upper Ludlow of the Trewerne Hills, but unfortunately I have been unable to trace its existence anywhere. It is not in the Geological Society's Collection, nor in the Museum of Practical Geology, London. I have enquired in several other Museums, but without result. His description and figure are hardly definite enough for a satisfactory comparison with other shells. There are numerous specimens in Prof. Groom's

<sup>1</sup> Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 1046.

<sup>2</sup> *Ibid.* p. 1054 & pl. lxxviii, figs. 19–21.

collection which appear to agree with the few characteristics given, more especially with the nature of the ornamentation: the keels being three in number on the penultimate whorl, and more numerous and closer below on the body-whorl. Although Sowerby's figure and description are so very incomplete, I nevertheless think it advisable to refer Prof. Groom's specimens to this species, as they resemble it more than any other British-described species belonging to the genus. Also they agree very nearly with specimens that I have seen from the Upper Ludlow elsewhere, as well as from the Aymestry Limestone, Wenlock Limestone, and Wenlock Shale, which have been referred to this species.

They also resemble those identified by Prof. Lindström with *Turbo carinatus*, Sow., the greater number coming near to his variety (*Cyclonema*) *glabrum*, which has fewer additional keels on the body-whorl.

The name *Turbo carinatus* seems to have been pre-occupied when J. de C. Sowerby thus named this species in the 'Silurian System,' 1839 (p. 612 & pl. v, fig. 28), for J. Sowerby had named a Greensand fossil *Turbo carinatus* in the 'Mineral Conchology' vol. iii (1821) pl. ccxl, fig. 3, and *Helix carinatus*, Sow., had been so called by Höninghaus in 1830 (in the Jahrbuch für Min. Geol., &c. p. 230).

In 1850, A. d'Orbigny, in his 'Prodrome de Paléontologie stratigraphique' (vol. i, p. 30) enters this species as *Turbo Octavia*, d'Orb., 1847. He gives no reason for the change of name; but it was probably changed in order to avoid confusion, on account of three different species having been called *Turbo carinatus*, and two (as has been shown) previous to Sowerby's description of the species under discussion. It therefore seems advisable to adopt d'Orbigny's specific name *Octavia*, as several succeeding palæontologists have done.

There is a certain amount of variation in the number and disposition of the keels on different individuals, but all agree in having the wider spaces above. Thus, there appear to be at least three, or perhaps four, well-marked varieties. The first, which seems to agree best with the type, has always two and sometimes three or more additional keels below on the body-whorl, as well as the strong ridge round the umbilicus; and there are three keels visible on the penultimate whorl besides the sutural keel, the second and third being closer than in the variety *glabrum*. In the Museum of Practical Geology, London, there is a specimen from the Upper Ludlow near Ludlow that might be referred here; and there is also one in the Manchester Museum, Owens College, from the Upper Ludlow of Whitcliff.

The second resembles this last variety so much, that it is sometimes difficult to decide to which a form should be referred; but there is as a rule only one additional keel, or rarely two, on the body-whorl, and but two strong keels are seen on the penultimate whorl besides the sutural one. This is the most abundant variety among Prof. Groom's specimens, there being about twelve examples, and it is probably the variety *glabrum* of Lindström. Here belong

three specimens in the Museum of Practical Geology: from the Bone-Bed, Mocktree, from the Aymestry Limestone of Botoyle, Caer Caradoc, and from that of Shucknall Hill, Woolhope, respectively. Also one in the British Museum (Natural History) from the Wenlock Shale of Gaercoed.

The third variety has a finer keel intercalated between the second and third keels, and four additional fine keels below on the body-whorl. There are two specimens of this in Prof. Groom's collection, and one in the Sedgwick Museum, Cambridge, from the Upper Ludlow Beds, Burton and Brockton.

The fourth variety is very different from the type. The second and third keels are placed so close together as to give the appearance of a Pleurotomarian band, only the lines of growth pass obliquely over it; and the base is much flattened, having two additional fine keels and two or three fine threads. There are two specimens of this in Prof. Groom's collection, and one in the Sedgwick Museum greatly resembles it; but it has eight fine keels below instead of two: it is from the Upper Ludlow of Woolhope.

For the third variety I would suggest the name *interstriatum*, and for the fourth *fasciatum*; this last differs most from the type, and may possibly prove a distinct species, but *interstriatum* comes very near the var. *glabrum*, Lind.

Dimensions.—The specimen figured in Pl. XXXVII, figs. 10 & 11, as possibly resembling the type, has the apex broken; the four existing whorls have a length of 12·5 millimetres, and the greatest width is 10 mm.

The variety *glabrum*, Lindström, figured in Pl. XXXVII, figs. 12 & 13, consists of five whorls in a length of 15 millimetres, and the width is 11 mm.

The best specimen of the variety *interstriatum* has only one whorl preserved, and it is not wholly exposed: its height = about 7·5 millimetres, and its width = about 8·75 mm. (See Pl. XXXVII, fig. 14.) A smaller example has two whorls in a length of 6·5 millimetres.

The biggest example of the variety *fasciatum* consists of about two whorls, which have a length of 9 millimetres, the greatest width being 12 mm. (See Pl. XXXVII, fig. 15.)

Horizon.—The typical form, as well as the varieties, occurs in (63) the Lower Ludlow, Aymestry Limestone included. The variety *glabrum* also is found in (90) the Wenlock.

Etheridge recorded this species as occurring in the Aymestry Limestone, Upper Ludlow, and doubtfully in the Wenlock Shale and Wenlock Limestone. According to Lindström, it is found in all the Silurian strata of Gothland.

### Family TURBINIDÆ, Alder.

#### Genus POLYTROPINA, nov.

*Euomphalus* (pars), J. Sowerby, 1814, 'Min. Conch.' vol. i, p. 113.

*Polytropis*, L. G. de Koninck, 1881, 'Faune du Calcaire Carbonifère de la Belgique' pt. iii, Ann. Mus. Roy. d'Hist. Nat. de Belg. vol. vi, p. 107.

*Oriostoma* (pars), G. Lindström (*non* Munier-Chalmas), 1884, 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vet.-Akad. Handl. vol. xix, No. 6, p. 156.

*Omphalotrochus*, K. A. Zittel, 1896 (*non* Meek, 1864), 'Text-book of Palæontology' translated by C. R. Eastman, vol. i, pt. i (1900) p. 447.

**Diagnosis.**—Shell discoidal, or depressed conical; spire short. Whorls convex, contiguous, ornamented by spiral keels and threads. Aperture subcircular; lips thin, generally continuous. Operculum thick, flat internally, conical externally. Umbilicus open, wide.

Type, *Polytropina discors* (Sow.).

**Remarks and Resemblances.**—In 1881 L. G. de Koninck gave the name *Polytropis* to a group hitherto included in *Euomphalus*, taking *E. discors*, Sow., as the type. It is distinguished from the typical *Euomphalus* by having no sinus in the outer lip. Unfortunately the name was preoccupied, for it had been given by C. L. F. Sandberger to a subgenus of *Valvata* in 1874.<sup>1</sup> De Koninck considered *Polytropis* identical with *Inachus*, Hisinger, but this name had been previously used by Leach. I therefore suggest the name *Polytropina* for the genus.

Lindström referred *Euomphalus discors* and other allied forms to *Oriostoma*, Munier-Chalmas;<sup>2</sup> but this genus, as described by Munier-Chalmas, is quite distinct, for the whorls of the spire and the umbilicus are disjoint, and the last whorl is very much larger than the others. Munier-Chalmas considered his genus to have affinity with certain species placed in *Platyceras* and *Tuba*.

Zittel referred *Euomphalus discors*, Sow. and *E. globosus* (Schloth.) to *Omphalotrochus*, Meek,<sup>3</sup> which genus he considered identical with *Polytropis*, de Kon. and *Oriostoma*, Lindström, but not with *Oriostoma* as originally defined by Munier-Chalmas. *Euomphalus Whitneyi*, the type of *Omphalotrochus*, appears to me quite distinct in its characters from either *E. discors*, Sow. or *E. globosus* (Schloth.), the whorls being ornamented by only two keels on the periphery, which give them a banded appearance; they are also flattened above and below, instead of being convex; the aperture is different; and the shell appears to have more in common with *Trochonema*. *Solarium antiquum*,<sup>4</sup> A. d'Orbigny, the other species referred by Meek to his genus, seems to agree with *Euomphalus Whitneyi*, but is quite distinct from *E. discors* and *E. globosus*.

#### POLYTROPINA GLOBOSA (Schloth.). (Pl. XXXVII, fig. 16.)

*Trochilites globosus*, Schlotheim, 1820, 'Die Petrefactenkunde' p. 162.

*Euomphalus funatus*, J. de C. Sowerby, 1823, 'Mineral Conchology' vol. v, p. 71 & pl. cccl, figs. 1-2.

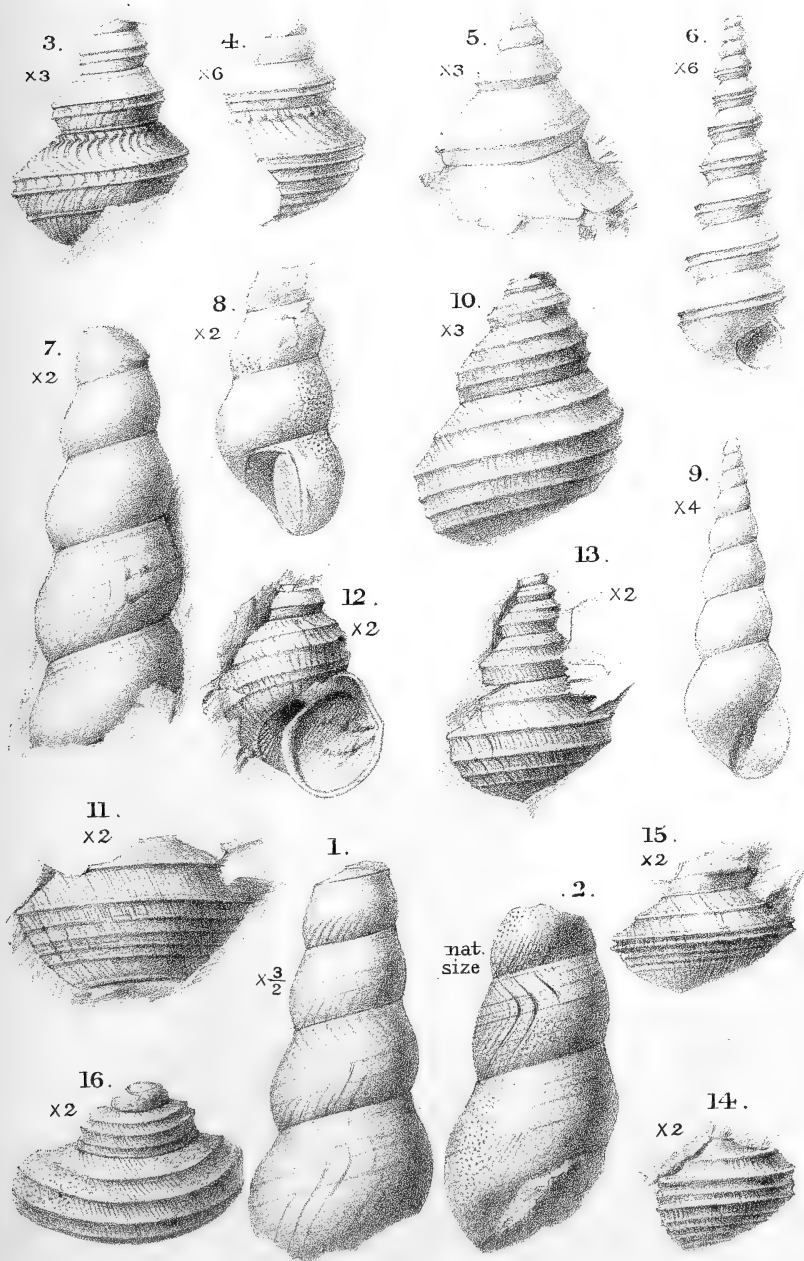
**Diagnosis.**—Shell conical; spire somewhat depressed, of about

<sup>1</sup> 'Die Land- & Süsswasser-Conchylien der Vorwelt' p. 697.

<sup>2</sup> Journal de Conchyliologie, vol. xxiv (1876) p. 103.

<sup>3</sup> 'Geol. Surv. California: Palæontology' vol. i (1864) p. 15 & pl. ii, figs. 8-8 a.

<sup>4</sup> 'Voyage dans l'Amérique Méridionale' vol. iii, pt. iv, Paléontologie (1842) p. 42 & pl. iii, figs. 1-3.



J. Donald del. F.H. Michael lith.

Bale & Danielsson. L<sup>td</sup> imp.

SILURIAN GASTEROPODA.



five whorls. Whorls convex, ornamented above by four strong keels, the intervening spaces unequal in width. Lines of growth distinct and close together, crossing the keels obliquely. Aperture subcircular. Umbilicus open, wide.

Remarks and Resemblances.—There are two examples of this form, the wax-impression of only one of which shows the ornamentation distinctly. The base of both is embedded in the matrix. On the body-whorl of the best-preserved specimen an additional keel is seen below the four, and there are traces of a fine thread in the middle of each of the two lower spaces. Sowerby's actual type of this species is wanting in his Collection in the British Museum (Natural History); but there are two specimens in it from the Wenlock Limestone (43623), which are marked *Euomphalus funatus* and agree with his description. I have compared the wax-impressions with these examples, and they appear to agree with them as well as with Sowerby's figures in the 'Mineral Conchology,' and also with other specimens in the general collection. Some of these show the aperture to be circular, also the operculum; the umbilicus is open and of moderate size, and there are at any rate four additional keels on the base; one or two specimens show also a fine intercalated thread between the keels. Lindström<sup>1</sup> considered *Euomphalus funatus*, Sow. identical with *Trochilites globosus*, Schlotheim. I am guided by his opinion in this, as he had the opportunity of examining Schlotheim's type in the Museum of the University of Berlin, an opportunity which I have not had.

Dimensions.—The length of the specimen figured (Pl. XXXVII, fig. 16) is 15·5 millimetres, and the width 11 mm.

Horizon.—(90) Wenlock.

Etheridge recorded *Euomphalus funatus* from the Upper Llandovery, the Woolhope Limestone, the Wenlock Limestone, and the Aymestry Limestone.

Lindström recorded this species from all the Silurian strata of Gothland.

#### EXPLANATION OF PLATE XXXVII *pars*.

- Fig. 3. *Plethospira (Ulrichospira) similis*, sp. nov. × 3. (See p. 569.)  
 4. *Bembexia* (?) *Groomii*, sp. nov. × 6. (See pp. 569–70.)  
 5. *Bembexia* (?) sp. × 3. (See p. 570.)  
 6. *Murchisonia (Goniostropha) Cambria*, sp. nov. × 6. (See p. 571.)  
 Figs. 7–9. *Loxonema Grindrodii*, Don. (?). Fig. 7. × 2. Fig. 8, front view. × 2. Fig. 9. × 4. (See p. 572.)  
 Figs. 10 & 11. *Gyronema Octavia* (d'Orb.). Fig. 10. × 3. Fig. 11, back view of base. × 2. (See p. 575.)  
 12 & 13. *Gyronema Octavia*, var. *glabrum*, Lindström. Fig. 12, aperture. × 2. Fig. 13, back view. × 2. (See p. 575.)  
 Fig. 14. *Gyronema Octavia*, var. *interstriatum* nov. × 2. (See p. 575.)  
 15. *Gyronema Octavia*, var. *fasciatum* nov. × 2. (See p. 575.)  
 16. *Polytropina globosa* (Schloth.). × 2. (See p. 577.)

<sup>1</sup> 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vet.-Akad. Handl. vol. xix (1881–84) No. 6, p. 162.

## DISCUSSION (ON THE TWO FOREGOING PAPERS).

Prof. GROOM said that students of Palæozoic stratigraphy constantly experienced difficulty in the determination of the imperfectly-known gasteropoda so abundant in many places, and they would be grateful to the Authoress for her useful contribution to the literature of the subject. It was true that the studies had been made on casts, and that casts were not so readily examined as fossils preserved in their original condition; but the perfect retention of the external form and minute details of ornamentation not uncommon in such cases was an advantage.



28. *On the IGNEOUS ROCKS occurring between ST. DAVID'S HEAD and STRUMBLE HEAD (PEMBROKESHIRE).* By JAMES VINCENT ELSDEN, B.Sc., F.G.S. (Read May 24th, 1905.)

## [PLATES XXXVIII-XL.]

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## I. INTRODUCTION.

THE area with which this paper deals adjoins the strip of coast lying between St. David's Head and Strumble Head in Pembrokeshire. No detailed account appears to have been given hitherto of the igneous rocks of the greater part of this district, but the Strumble-Head rocks have been described by Mr. F. R. Cowper Reed in his paper on the geology of the Fishguard District.<sup>1</sup> Adjoining parts of the county have also received attention: Mr. John Parkinson has discussed the Prescelly area,<sup>2</sup> and the district south of St. David's, including Skomer Island, has been described by various writers in considerable detail.<sup>3</sup> The granitic rock of St. David's, of classic interest by reason of its disputed igneous origin, has been the subject of exhaustive discussion by Henry Hicks,<sup>4</sup> and has been described petrographically by Thomas Davies,<sup>5</sup> E. B. Tawney,<sup>6</sup> Prof. Bonney,<sup>7</sup> Sir Archibald Geikie,<sup>8</sup> the Rev. J. F. Blake,<sup>9</sup> and Prof. C. Lloyd Morgan.<sup>10</sup> Murchison made some reference to the trap-rocks of Pembrokeshire in his well-known memoir,<sup>11</sup> and these rocks were mapped on the 1-inch scale by the

<sup>1</sup> Quart. Journ. Geol. Soc. vol. li (1895) p. 149.

<sup>2</sup> 'Igneous Rocks in North Pembrokeshire' Quart. Journ. Geol. Soc. vol. liii (1897) p. 465.

<sup>3</sup> See F. Rutley, 'The Felsitic Lavas of England & Wales' Mem. Geol. Surv. (1885) pp. 16, 18; J. J. H. Teall, 'British Petrography' 1888, pp. 222, 284, & 336; and F. T. Howard & E. W. Small, Rep. Brit. Assoc. 1893 (Nottingham) p. 766.

<sup>4</sup> Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 167; vol. xxxiii (1877) p. 229; vol. xxxiv (1878) pp. 147, 153; and vol. xl (1884) p. 507.

<sup>5</sup> *Ibid.* vol. xxxiii (1877) p. 231, footnote.

<sup>6</sup> Proc. Bristol Nat. Soc. n. s. vol. ii, pt. ii (1878) p. 112.

<sup>7</sup> Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 155, footnote.

<sup>8</sup> *Ibid.* vol. xxxix (1883) p. 313.

<sup>9</sup> *Ibid.* vol. xl (1884) p. 302.

<sup>10</sup> *Ibid.* vol. xlv (1890) p. 241.

<sup>11</sup> 'The Silurian System' 1839, p. 401.

Geological Survey in 1845, under the superintendence of Sir Henry de la Beche, the igneous rocks being re-surveyed in 1855-56 by W. T. Aveline.

Of the stratigraphy of this portion of Pembrokeshire there is still much to learn. Hicks mapped the outcrops between St. David's and Aberiddy Bay,<sup>1</sup> and Mr. Cowper Reed has done the same for the neighbourhood of Fishguard.<sup>2</sup> These lines are approximately shown in the accompanying sketch-map (Pl. XXXVIII). There is, however, a good deal of uncertainty with regard to the intervening area, and the scarcity of fossils increases the difficulty of any attempt to fill in the stratigraphical details necessary to complete the survey of this part of the county, although good exposures are not lacking, both in the fine coast-section and in numerous inland quarries. A prominent feature in the area under discussion is the fault running in a south-easterly direction from Pwll-Strodyr on the coast, about 1 mile east of Abercastle, and truncating a series of narrow sills which strike east and west between Abercastle and Mathry. This fault, together with the great east-and-west fault extending from St. David's to near St. Edren's, isolates a triangular wedge of country from the adjoining district of Strumble Head on the one side, and the pre-Cambrian area of St. David's on the other. In this triangle the *Lingula*-Flags, Tremadoc Beds, Arenig and Llandeilo Beds, form successive bands striking east and west. There are other minor faults, which, however, do not need further description for the purpose of this paper. The Upper Llandeilo strata, which the late Dr. Hicks recognized on the north of Aberiddy Bay, seem to extend over the district of Barry, but from this point northward to Strumble Head the sequence is obscure. Bala Beds probably occupy the greater part of the area between Trevine and Strumble Head, although the outcrops appear to have been considerably displaced by the Pwll-Strodyr Fault.

## II. THE CONTEMPORANEOUS IGNEOUS ROCKS.

The sequence of the volcanic rocks of North Pembrokeshire has been already established over a considerable part of the area under discussion, but to what extent Arenig lavas are represented is still imperfectly known. Mr. Parkinson was not able to establish definitely the age of the Prescelly lava-flows, which may possibly date from Arenig time, and several bands of contemporaneous volcanic rock are mapped, in strata presumably of this age, in the southern portion of the triangle mentioned above. I shall, however, at a later stage (p. 599), advance reasons for doubting the contemporaneous character of some, at least, of these exposures in the neighbourhood of the Pwll-Strodyr Fault.

The most conspicuous of the true lava-flows in this portion of the district are seen in the neighbourhood of Llanrian, where

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxi (1875) pp. 167 *et seqq.*

<sup>2</sup> *Ibid.* vol. li (1895) pp. 149 *et seqq.*

the lowest beds, exposed as tuffs on the south of Abereiddy Bay, were taken by Hicks as the base of the Llandeilo Series. These outbursts are, therefore, of the same age as the lowest volcanic series of Fishguard, as described by Mr. Cowper Reed. The higher Llanrian lavas correspond with those of Goodwick, and are of Upper Llandeilo and Bala age. Examination of these Llanrian lavas shows them to be thoroughly acid in character, and to resemble, in a general sense, those of the Fishguard and Prescelly areas. By the courtesy of Mr. Parkinson, I have been able to compare his slices of the Prescelly lavas with my own specimens from the Llanrian district, with which (except that I have not noticed very pronounced spherulitic structures at Llanrian) they agree fairly well. There does not seem to be any reason to doubt that, from a petrographical point of view, the eruptive rocks of the Prescelly, Fishguard, and Llanrian areas are of similar type. My Llanrian specimens may be briefly described as containing phenocrysts of quartz and monoclinic feldspar in a microfelsitic matrix; but, in view of the very detailed descriptions of similar acid lava-flows given by Mr. Cowper Reed and Mr. Parkinson, I do not think it necessary, for the purpose of the present paper, to dwell further upon this portion of the subject.

Higher in the Bala Series come the thin volcanic beds of Porth Sychan and Porth Melyn on Strumble Head, of which I have noticed no equivalents farther along the coast to the south-west.

Some of the exposures mapped by the Geological Survey as contemporaneous lavas, in the neighbourhood of the Pwll-Strodyr Fault, are of a character totally different from these acid lava-flows. I allude to certain exposures in the neighbourhood of Mathry, to which reference will again be made in another section of this paper (p. 599).

### III. THE INTRUSIVE ROCKS OF STRUMBLE HEAD AND THE ADJOINING DISTRICT.

An extensive series of intrusive basic rocks breaks through both the lavas and sedimentary rocks of the Fishguard district. These are described in Mr. Cowper Reed's paper, and very similar rocks are described by Mr. Parkinson from the Prescelly area. I need not, therefore, enter into details of these rocks, more than is necessary to illustrate their relation to the intrusive rocks of the district farther to the south-west. The prevailing type is a normal diabase, more or less ophitic, without olivine, and with an abundance of chlorite and epidote. They are moderately-basic rocks, and my observations tend to confirm Mr. Cowper Reed's statement that the feldspars generally belong to the oligoclase-andesine series. Very often, however, they are too much altered for optical determination. A typical development of this rock occurs at Llanwnda, near Goodwick, where an extremely coarse-grained variety of the gabbro-type is capriciously intermingled with the ordinary type. I shall refer to the general type of these basic intrusives as the Llanwnda type, in which I include both the Fishguard and the Prescelly rocks.

The large mass lying along the northern coast of Strumble Head differs from this type in being a uniformly fine-grained basaltic rock, distinctly columnar at Pen Anglâs, and in places tachylytic. Along the southern margin, from Penrhiw, near Goodwick, to Porth Melyn, it is amygdaloidal or vesicular, and often it closely simulates a true surface-flow. At its western end it has been considerably sheared, as may be seen at Trevishec and at Rhos-yn-wen. On the Geological-Survey map this rock is merged in the Llanwnda rock, but I saw no actual junction in the field, nor any sign of the passage of this fine-grained basalt into the very coarse Llanwnda type: Mr. Cowper Reed, in fact, refers it to a later period.

We may now proceed to trace a variation in the basic type, referred to above, which appears to possess considerable interest in view of the character of the intrusive rocks occurring farther south. For this purpose, it will be convenient to describe in more detail the group of intrusions lying immediately to the west of Llanwnda, between Pont Iago and Porth Melyn. This group forms a well-defined range of hills rising into the conspicuous summits of Y Garn, Garn Bolch, Garn Gilfach, Garn Fechan, and Garn Fawr.

If we begin the examination of this ridge at Y Garn near Pont Iago, we find that the rock, although microscopically indistinguishable from the medium-grained Llanwnda type, shows under the microscope the gradual appearance of a rhombic pyroxene. The ophitic augites also give place to a more pronounced idiomorphic type. Some of the crystals of augite appear to be of earlier consolidation than the felspar; and a later generation, penetrated by felspar-laths, includes remnants of a rhombic pyroxene, some of which is intergrown with the earlier generation of augite. The rhombic pyroxene has undergone the usual bastite-alteration, and includes numerous granules of brown sphene.

At Garn Bolch a rock of coarser grain shows, in addition to the above-described characters, zoned feldspars, and also feldspars of a later generation with a lower refractive index. These rocks, which approximate to enstatite-diorite in character,<sup>1</sup> are penetrated by dykes of a finer-grained rock, with granular augite, no enstatite, and a considerable proportion of magnetite, the last-named mineral being replaced in the main mass by ilmenite.

Proceeding to Garn Gilfach we find a typical dolerite, with ilmenite, magnetite, and phenocrysts of felspar and augite, the groundmass containing square sections of untwinned felspar, augite, and an abundance of magnetite. This rock bears a close resemblance to the dykes which penetrate Garn Bolch.

We now come to Garn Fechan, where the dominant rock is the variolite, so fully described by Mr. Cowper Reed. It is important

<sup>1</sup> The term enstatite is used in a general sense, to denote both the unaltered and the altered forms of this mineral, and to include also the more ferri-ferous varieties, known generally as bronzite and hypersthene.

to note, however, that this mass contains an enstatite-bearing rock, with quartz and micropegmatite, the relation of which to the variolite is not very clear.

Finally, at Garn Fawr the base of the hill is a coarse-grained doleritic rock with two generations of both felspar and augite, no rhombic pyroxene, and differing from the rock of Garn Gilfach only in the scarcity of magnetite. The summit of the hill is crowned by a tachylytic rock (described by Mr. Cowper Reed), which, from its pronounced columnar structure, seems to be intrusive in the main mass, or, at any rate, subsequent to the coarse rock at the base of Garn Fawr.

The above-described facts seem to point to the conclusion that this ridge is a composite intrusion. Mr. Cowper Reed explains the occurrence of the granophyric enstatite-bearing rock of Garn Fechan, as due to the incorporation of the acid lava which it penetrates. The analyses tabulated by him<sup>1</sup> show so low a percentage of magnesia in the acid lavas, that it is difficult to understand, upon chemical grounds, how its incorporation could lead to the development of enstatite in a rock which carries no olivine in its normal state. On the other hand, the experimental work of Prof. Vogt has demonstrated that an ordinary non-olivine-bearing diabase-magma might be expected to develop enstatite if enriched by silica and magnesia.<sup>2</sup> I am inclined, therefore, to associate this occurrence with that of the enstatite-diabase of Garn Bolch and Y Garn, and will leave its interpretation to a later stage. The point which I wish to emphasize at present is the occurrence, in this ridge, of rocks differing from the Llanwnda type, and marked by the incoming of a rhombic pyroxene.

Proceeding next to the St. Nicholas district, a large intrusion is observed on the coast at Llech Dafad. The rock here varies much in grain. The coarsest variety forms irregular streaks and patches in a finer-grained matrix. The coarse rock is paler in colour, owing to a scarcity of ilmenite and other dark minerals, which, as in most of the specimens hereafter to be described, is not confined to the minerals of first consolidation. Enstatite occurs in all the slices to a variable degree, and it always precedes augite in order of crystallization. The rock does not differ greatly from that of Garn Bolch, but apatite is more conspicuous. It is an enstatite-diabase.

At Tresseysilt, close by, is another intrusion of a more variable character. A conspicuous variety recalls the coarse-grained Llanwnda type, but the felspars are more resistant to atmospheric weathering, and stand out in bold relief on the exposed surface. Under the microscope, enstatite can be recognized in all varieties, in some cases as bastite-pseudomorphs, in other cases altered to an

<sup>1</sup> Quart. Journ. Geol. Soc. vol. li (1895) p. 177.

<sup>2</sup> 'Die Silicateschmelzlösungen' pt. i, pl. i (Christiania, 1903).

almost isotropic substance with pyroxene-cleavages, and sometimes still retaining the usual pleochroism of ferriferous varieties of this mineral. The felspars are mainly of a more acid species than those found in the Llanwnda type. They commonly have a lower refractive index than balsam, are often untwinned, occurring in broad rectangular plates, and a little microcline is sometimes recognizable. The augite does not differ from the normal type. Quartz and apatite are conspicuous in the more acid types. Differentiation *in situ* seems to have taken place to a considerable extent, with corresponding variations in mineralogical characters. The rock is not sufficiently well exposed to establish any progressive change from margins to centre, although probably this is the case. Secondary changes have often obscured the original character of the rock, leading to extensive developments of chlorite, epidote, and zeolitic substances. The rock seems, on the whole, to vary from an enstatite-diorite to an enstatite-diabase.

As we proceed eastward to Trellys, the character of the rock is seen again to pass into the normal Llanwnda type, which is preserved through Panteg to Manorowen.

So far as the Strumble-Head district is concerned, I have confined myself to an endeavour to show that the diabases of Fishguard and Prescelly (although remarkably uniform in character in those areas), when traced westward show local variations, characterized by a tendency to greater acidity and a development of enstatite. These changes, which are most pronounced in Garn Bolch, Garn Fechan, Llech Dafad, and Tresseysilt, are of such a nature as to suggest the intrusion at these localities of a magma of different composition from the typical diabase-magma of the eastern intrusions.

It will now be necessary to describe the intrusions on the south-west side of the Pwll-Strodyr Fault; and, as it seems to conduce to greater clearness to attack this region from the extreme south-western end, I will next discuss the St. David's-Head rocks, which lie about 12 miles from the above-mentioned fault.

#### IV. THE INTRUSIVE ROCKS OF ST. DAVID'S HEAD AND THE ADJOINING DISTRICT.

The existence of a quartz-gabbro with rhombic pyroxene at St. David's Head has long been known, but no very detailed account of it has yet been published. Mr. Harker, speaking of a specimen from this district, calls attention to its identity with the rock of Carrock Fell, with the exception that the highly-basic modification found in the latter district had not then been noted in the St. David's-Head rock.<sup>1</sup> The most basic variety in my specimens from this

<sup>1</sup> 'Petrology for Students' 1895, p. 66.

area were taken from the western extremity of Carn Llidi. The dominant rock is holocrystalline, of medium grain, and showing considerable variation in colour, according to the proportions of feldspars and ferro-magnesian minerals present. The specific gravity of the dark variety was ascertained to be 2.98. Under the microscope, the rock is seen to consist mainly of feldspar, pyroxene, biotite, and iron-ores. The feldspars give extinctions corresponding to a composition varying from  $Ab_2An_1$  to  $Ab_1An_1$ , and are of a thoroughly-basic species. Pyroxene is present, in both rhombic and monoclinic forms. The rhombic pyroxene is a fibrous, brownish, bastite-modification of enstatite. It is sometimes of earlier, and at other times of later, consolidation than the augite, with which it is also occasionally intergrown. The augite is brown, granular, and sometimes rather unalitized. It possesses the basal striation so often seen in this class of rock, and twins of the ordinary type, sometimes showing 'herring-bone' structure, are common. Biotite is moderately abundant, and crystallized after the feldspar. The iron-ore is ilmenite, now largely converted into opaque leucoxene and sphene. Quartz is very sparingly present, and seems to be wanting in some varieties. Apatite, also, is apparently absent. The basic character of this rock and the abundance of rhombic pyroxene seem to place it among the norites, using that term as defined by Prof. Zirkel.<sup>1</sup> (See Pl. XXXIX, fig. 1.)

Along the ridge towards the eastern shoulder of Carn Llidi the rock becomes less basic. Quartz-areas begin to appear, and, although my specimens do not here show any micropegmatite, the quartz-areas are invariably associated with rectangular untwinned feldspars, having a lower index of refraction than quartz. These appear to be orthoclase. The long laths, on the other hand, which penetrate the pyroxenes, seem to be of a basic kind. The rock exhibits in a marked degree a tendency to the aggregation of enstatite in one portion of the slide and augite in another. A similar peculiarity in hypersthene-rocks has been remarked by other observers.<sup>2</sup> Both fibrous enstatite and augite occur in large plates, interpenetrated by feldspar-laths (see Pl. XXXIX, fig. 2). The augite also occurs in more idiomorphic forms, which are nearly always twinned. Biotite gradually disappears with increasing acidity, and apatite becomes very plentiful. The norite here passes into a quartz-norite or, as some would describe it, an enstatite-diorite.

Following the outcrop of this ridge to Carnedd Givian, a similar character is observed. Quartz-areas are associated with broad rectangles of untwinned feldspar showing a low refractive index,

<sup>1</sup> Dr. Teall, in describing the Galloway granites, prefers the term hyperite for basic, holocrystalline rocks containing both rhombic and monoclinic pyroxene. See 'The Silurian Rocks of Britain' Mem. Geol. Surv. vol. i (1899) p. 613.

<sup>2</sup> T. H. Holland, 'The Charnockite-Series' Mem. Geol. Surv. India, vol. xxviii (1900) p. 152; also F. H. Hatch, Quart. Journ. Geol. Soc. vol. xlv (1889) p. 344.

but there is still an absence of micropegmatite, and the augite retains a pronounced basal striation. There is also an apparent absence of original hornblende in the slices examined.

From St. David's Head a ridge extends along the coast, parallel to that of Carn Llidi. Specimens taken at intervals along this ridge show considerable variations in texture. A very coarse-grained variety, recalling in the field the coarse rocks of Llanwnda and Tresseysilt, seems to be capriciously intermixed with varieties of finer texture. All these varieties exhibit more or less micropegmatite, which is often very conspicuous. Associated with the micropegmatite and quartz are untwinned feldspars, with a lower refractive index than quartz or balsam. Plagioclase with albitestriation is also present, and the extinctions point to a species of andesine. Rhombic pyroxene is abundant, generally in large plates, often intergrown with augite and penetrated by feldspar-laths. The relative proportions of rhombic and monoclinic pyroxenes are very variable, one or the other variety preponderating in different slides, or in different portions of the same slide. The rhombic pyroxene is invariably fibrous, and is occasionally brown and slightly pleochroic, but never approaches the character of typical hypersthene. The augite is commonly twinned in simple binary combinations, but more complex twinning is also occasionally seen, the twinning-plane being then oblique to the trace of the vertical cleavage. Basal striation is still conspicuous in some slides. Biotite is absent from all the slices, but a little original, compact, green hornblende may be recognized in some of the specimens from the more easterly portions of the mass. Apatite is present, often in conspicuous quantity, and the iron-ore is invariably ilmenite, sometimes showing good crystalline outlines, with rhombohedral faces, but generally altered to leucoxene or sphene. On the whole, the changes noticeable along this ridge in a north-easterly direction seem to indicate a gradual increase in acidity, with the incoming of hornblende in addition to the rhombic and monoclinic pyroxenes. It differs, also, from the Carn-Llidi intrusion in the abundant development of micropegmatite and an increased proportion of an acid feldspar, which appears to be orthoclase. The rocks, therefore, would appear to graduate towards the class of enstatite-diorites, although there is still a preponderance in places of a rhombic pyroxene.

East of Carn Llidi, at a distance of about half a mile, is another ridge, about a mile in length, which rises into the rocky eminences of Carnedd Lleithr, Carn Perfedd, Carn Ffald, and Carn Trelwyd. Here the rock is of finer grain, and macroscopically very uniform, looking much like a grey granite.

At Carnedd Lleithr, a specimen from the south-western corner shows under the microscope a considerable amount of quartz and micropegmatite, the latter often framing the feldspar-crystals in the typical manner. The feldspars projecting into the quartz-areas all have a lower refractive index than quartz, and are generally



untwinned. These appear to be orthoclase. Some of the sections show an outer zone of more acid composition than the interior. Both augite and enstatite are much reduced in quantity, and the chief ferromagnesian mineral is a strongly-pleochroic brownish hornblende. The scheme of pleochroism is :

$\alpha$ , pale brownish-yellow;  $\beta$ , light-brown;  $\gamma$ , dark greenish-brown;  $\gamma > \beta > \alpha$ .

The extinction-angle is about  $15^\circ$  on clinopinacoid sections. Augite occurs very sparingly, and the enstatite seems to be rather more ferrikerous, distinctly pleochroic, and sometimes altered into a fibrous amphibole on the margins. All the dark minerals seem to have preceded the feldspars in order of consolidation. The latter apparently grew more acid, until finally the eutectic point of orthoclase and quartz was reached. The iron-ores are represented by ilmenite, rather altered. Apatite is abundant, and there is some secondary epidote. In another specimen, of finer grain, the order of consolidation is apparently different, feldspar preceding both enstatite and augite; with hornblende, reduced in quantity, immediately preceding the quartz and micropegmatite. (See Pl. XXXIX, fig. 5.)

At Carn Ffald the rock is very similar, but there is less quartz and micropegmatite; and at Carn Perfedd the latter structure appears to be absent, but neighbouring interstitial quartz-areas extinguish simultaneously, and are penetrated by a feldspar having the appearance of orthoclase. This character is still more pronounced at Carn Trelwyd, where orthoclase seems to be more plentiful, both simple and in Carlsbad twins. The earlier feldspars are polysynthetic, with extinctions corresponding to andesine. Some augite preceded the feldspars, which enclose it in pœcilitic fashion. Augite also occurs in good octagonal sections. Enstatite is about equal in quantity to the augite, and occurs in small fibrous pseudomorphs, slightly pleochroic. Hornblende is rather plentiful, and has an idiomorphic habit which becomes more pronounced in the quartz-areas. Ilmenite is scarcer than usual, but apatite is very abundant. Quartz-areas are associated with orthoclase, the latter in idiomorphic crystals, but there is no micropegmatite visible in the specimens examined.

The rocks in this ridge appear to belong generally to the class of enstatite-diorites.

The apparent abundance of orthoclase in the Carn-Trelwyd rock almost suggests a monzonite, and I determined the alkalies in this rock, with a view to the estimation of the relative amounts of orthoclase and plagioclase present. The following was the result:—

Per- centage.	Molecular proportion.
$\text{Na}_2\text{O} = 3.726$ .....	0.60
$\text{K}_2\text{O} = 2.073$ .....	0.22

The orthoclase calculated from these data would thus form 12.232 per cent. of the rock, which is scarcely high enough to

warrant the placing of this rock among the monzonites; but, as the feldspars are rather altered, only surface-exposures being accessible, it is possible that some alkali has disappeared. From a general point of view, I think it may be stated that the rocks in this ridge vary from quartz-enstatite diorite towards quartz-enstatite monzonite, and typical examples of the latter rock might be expected to occur locally. There is certainly a marked difference between the intrusions along this ridge and the biotite-norites of Carn Llidi. The prominence of hornblende also differentiates them from the rocks of St. David's Head, in which hornblende seems to occur only sparingly towards the eastern extremity. Rhombic pyroxene, however, continues to be a characteristic and abundant component of the rock.

We come next to Penberry Hill, which is an isolated boss-like intrusion, lying in direct line with, and about a mile to the north-east of, the Carn-Trelwyd ridge. Under the microscope this rock bears some resemblance to that of Carn Trelwyd, but it is evidently of a more basic type, containing less quartz and orthoclase, and only a very insignificant amount of hornblende. The feature of this rock is the predominance of a bronzite-form of enstatite, which occurs in very numerous rectangular sections, with ill-defined terminations, sometimes showing rather indistinct blunt domes at one end. It is fibrous and slightly pleochroic, and seems to belong to an early period of consolidation—preceding, in fact, all the constituents except apatite (which is fairly plentiful) and some of the ilmenite. It closely resembles the enstatites above described, and has a tendency to enclose sphene-granules. The next mineral to crystallize was feldspar, which seems to be a not very-basic plagioclase, but is rather too turbid for accurate determination. This was followed by a pale augite in subordinate amount, sometimes twinned and rather granular. There seems to be some orthoclase, with occasional Carlsbad twinning; and quartz with a very little micropegmatite were the last minerals to crystallize. (See Pl. XXXIX, fig. 3.)

I made a chemical analysis of this rock with the following results:—

	Percentage.	Molecular proportion.
Silica .....	54.42	.902
Titanic acid .....	0.72	.009
Alumina.....	15.34	.151
Iron-sesquioxide .....	0.67	.004
Iron-monoxide .....	5.17	.071
Manganese-oxide .....	trace	
Lime .....	8.30	.148
Magnesia .....	6.69	.166
Potash .....	1.01	.010
Soda .....	4.21	.068
Phosphoric acid .....	0.57	.004
Water expelled at 110° Centigr.....	0.47	
Water (combined) .....	2.60	
Carbon-dioxide .....	trace	
	<hr/> 100.17 <hr/>	

The felspars are rather turbid, and the rock is evidently somewhat altered, but the analysis corresponds approximately to the following percentage mineral-composition, omitting water:—

Quartz.....	1·740	} Constituting an oligo- clase-andesine of com- position $Ab_2An_1$ .
Orthoclase .....	5·560	
Albite .....	35·632	
Anorthite .....	17·514	
Enstatite .....	17·028	
Hornblende and augite .....	16·716	
Ilmenite and magnetite .....	2·296	
Apatite .....	1·240	
	<u>97·726</u>	

In arriving at the foregoing result there is, of course, the usual difficulty with regard to the composition of the pyroxenes and amphiboles, which I have calculated as diopside, with the addition of a small proportion of Tschermak's molecule  $CaO \cdot Al_2O_3 \cdot SiO_2$ . As, however, some soda-molecules should probably be included, the albite is, in consequence, too high, and the quartz too low. It is interesting to compare the percentage composition of this rock with some quartz-enstatite rocks of this and other countries:—

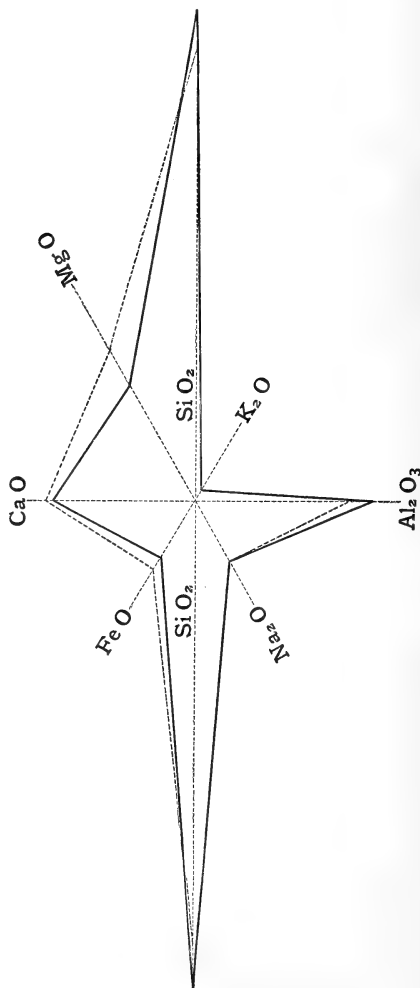
	I.	II.	III.	IV.	V.	VI.
Silica.....	54·42	58·45	53·50	50·71	54·03	56·72
Alumina .....	15·34	17·08	22·20	14·78	16·71	16·90
Ferric oxide.....	0·67	0·76	3·60	3·52	1·37	4·14
Ferrous oxide .....	5·17	4·61	2·64	8·95	7·70	6·28
Magnesia .....	6·69	5·15	2·00	5·90	5·66	4·62
Lime .....	8·30	7·60	9·45	8·21	8·84	7·25
Soda .....	4·21	4·25	4·26	2·76	2·99	4·65
Potash .....	1·01	1·02	0·61	1·39	0·67	0·63
Water at 110° Centigr. ...	0·47	0·12	...	...	0·14	...
Water (ignition) .....	2·60	0·95	1·50	1·78	0·53	0·75
Titanic acid .....	0·72	n.d.	0·45	1·92	0·84	...
Phosphoric acid .....	0·57	n.d.	...	...	0·13	...
	<u>100·17</u>	<u>99·99</u>	<u>100·21</u>	<u>99·92</u>	<u>99·61</u>	<u>101·94</u>

- I. Quartz-norite of Penberry Hill. Author's analysis.\*
- II. Enstatite-diorite, Penmaenmawr. Analysis by J. A. Phillips, Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 424.
- III. Gabbro of Carrook Fell. Analysis by G. Barrow, Quart. Journ. Geol. Soc. vol. 1 (1894) p. 323.
- IV. Enstatite-diabase, Whin Sill. Analysis by J. J. H. Teall, Quart. Journ. Geol. Soc. vol. xl (1884) p. 654.
- V. Hypersthene-gabbro, Pennsylvania. Analysis by W. F. Hillebrand, U. S. Geol. Surv. Bull. No. 228 (1904) p. 48.
- VI. Hypersthene-norite, Oberhofen (Tyrol). Analysis by F. Teller & C. von John, Jahrb. d. k.-k. Geol. Reichsanst. vol. xxxii (1882) p. 647.

The close agreement which this Penberry-Hill rock exhibits with that of Penmaenmawr is evident from a comparison of the analyses. This is graphically represented in the accompanying diagram (fig. 1, p. 590) drawn upon Brögger's familiar plan. The Penmaenmawr rock, however, has no hornblende, and a little biotite is occasionally

present. The agreement would have been still closer, if the alumina of the Penmaenmawr rock had been diminished by the determination of titanitic and phosphoric acids, especially if allowance be made for the water of hydration in the Penberry-Hill sample. The Carrock-Fell hypersthene-gabbro has considerably less rhombic pyroxene, and

Fig. 1.—Diagram illustrating the difference in composition between the rocks of Penmaenmawr and Penberry Hill.



[The continuous line represents the Penmaenmawr rock, and the broken line the Penberry-Hill rock.]

there is a corresponding deficiency in magnesia. The Whin-Sill rock contains more iron and a smaller percentage of alkalies and silica.

On the whole, the composition of the Penberry-Hill rock seems to entitle it to a place among the quartz-norites, described by

F. Teller and C. von John.<sup>1</sup> It seems advisable to retain this term, for the sake of clearness of description, in order to distinguish rocks which appear to occupy a place between the normal diorites and the norites. Examples of similar gradations from true norites into quartz-bearing rhombic pyroxene-rocks have been described from other localities in addition to the Tyrol; as, for example, in the Charnockite Series of India,<sup>2</sup> at Ekersund in Norway,<sup>3</sup> and elsewhere. The nomenclature of enstatite-bearing rocks of this type has been a widely-felt difficulty, and has been much discussed by writers on rock-classification.<sup>4</sup> It appears desirable to adopt the term quartz-norite, to include the enstatite-bearing equivalent of the quartz-gabbros, in preference to the introduction of a new name, as has been proposed by Mr. J. E. Spurr in describing the so-called belugite (or norite-diorite) of Alaska.<sup>5</sup> The need for a class-name of this sort is especially felt in cases like the present, in which rocks rich in enstatite are associated with normal diorites wherein rhombic pyroxene becomes distinctly subordinate to hornblende.

Near the northern flank of Penberry Hill a long, irregular, narrow intrusion extends from Trwyndiallt in an east-north-easterly direction to near Llanvirn. Specimens from this intrusion, taken at Pen Clegyr, show very similar characters to the eastern portion of the Carn-Llidi mass, of which it may possibly be a continuation.

In the neighbourhood of Portheiddy Common are several thin intrusions, which have a distinctly more basic character. The felspars are in large rectangles, penetrating ophitically now augite, now enstatite. In some parts the latter mineral predominates and occurs in various stages of alteration from an almost unaltered yellowish or colourless variety to the usual fibrous form, but always preceding augite in order of crystallization. Chlorite is fairly abundant. Quartz is practically absent, and apatite is very sparingly represented. The iron-ore is ilmenite, which is not much altered. It would seem that we have here an enstatite-diabase with a tendency to a predominance of enstatite, and differing only from a norite in its ophitic tendency.

On ascending the hill north of Aberiddy Bay, several other basic dykes are seen along the edge of the cliff. Specimens from these exposures possess very much the same character as those above described, but do not form very satisfactory objects for microscopic examination, on account of the large quantity of secondary alteration-products. Despite the confused structure, however, the

<sup>1</sup> 'Geologisch-petrographische Beiträge zur Kenntniss der dioritischen Gesteine von Klausen in Südtirol' Jahrb. d. k.-k. Geol. Reichsanst. vol. xxxii (1882) pp. 589 *et seqq.*

<sup>2</sup> Mem. Geol. Surv. India, vol. xxviii (1900) pp. 125 *et seqq.*

<sup>3</sup> J. H. L. Vogt, Zeitschr. für prakt. Geol. vol. i (1893) p. 4.

<sup>4</sup> See F. Löwinson-Lessing, 'Kritische Beiträge zur Systematik der Eruptivgesteine' Tschermak's Min. & Petr. Mitth. n. s. vol. xxi (1902) p. 311.

<sup>5</sup> 'American Geologist' vol. xxv (1900) p. 233.

presence of enstatite is clearly established, and the rocks can be assigned to the class of enstatite-diabases.

At Penclegyr, to the east of Porth Gain, is a large boss-like intrusion which has been extensively quarried. The rock is bluish-grey and of a more compact character than that of Penberry Hill. Slices from different parts of this mass show two principal modifications. In the first variety, which is the rock exposed in the quarry on the northern face of the cliff, there is a close resemblance to the rock of Penberry Hill. The minerals present are apatite, ilmenite, augite, felspar, rhombic pyroxene, and quartz. Apatite is abundant. The augite clearly precedes both the felspar and the rhombic pyroxene. It is granular, and is included in, or moulds, both the last-named minerals. Rhombic pyroxene, however, crystallized later than the felspar, by which it is penetrated. It occurs in rather ragged rectangular sections, and is faintly pleochroic. A large portion of the felspar has rather a low refractive index and a symmetrical extinction of nearly  $20^\circ$  in twins on the albite-plan: it is, therefore, probably albite. A little orthoclase of later crystallization appears to be present. Quartz is fairly abundant in small interstitial grains, clusters of which extinguish simultaneously, but there is no micropegmatite. From its greater acidity this rock may therefore be classed as a quartz-enstatite diorite.

In another variety of the rock augite is completely wanting, and quartz seems to be present in reduced amount. The bulk of the rock consists of plagioclase and a pale yellow pseudomorph after enstatite. The felspar resembles the species above mentioned, and probably is mainly albite, but a little orthoclase is doubtfully recognizable. It preceded the enstatite, which is interstitial to it. Apatite is moderately abundant, and there is some opaque iron-ore in rather irregular patches. I made a partial chemical analysis of this rock, with the following results:—

	<i>Per cent.</i>
Silica .....	61.45
Alumina, iron, etc. ....	24.80
Lime .....	0.85
Magnesia .....	2.91

(The specific gravity of the rock is 2.68.)

The summation leaves about 10 per cent. for alkalis and water. The small proportion of lime is significant, and explains the absence of augite in this variety, as well as the character of the bulk of the felspar. Taken in conjunction with the fact, that in the main mass the augite crystallized before the felspar, the explanation might be that this portion of the magma has been derived by a process of liquation from another portion in which augite had already crystallized; or, perhaps, it may represent a magma from which augite-crystals had been removed by gravitation to a lower stratum. I am at a loss for a class-name for this albite-enstatite rock, which seems to be of rather an abnormal type. (See Pl. XXXIX, fig. 4.)

We pass now to the series of thin parallel intrusions in the neighbourhood of Trevine, several of which emerge on the shore at Aberfelin. One of these, near the footpath leading to the beach, bears a close resemblance to the variety described above. The bulk of the rock consists of felspar, which, however, is associated with a rather abundant groundmass of micropegmatite and quartz. The extinctions and refractive index again point to albite as the dominant species, the orthoclase being confined to the micropegmatite. Some enstatite in rather fragmentary, much altered shreds seems to be present, and there are irregular strings of ilmenite and leucoxene, with a few specks of pyrites. Apatite is still fairly abundant. Secondary patches of calcite are present, and a little vermicular chlorite resembling the species which has been described as *helminth*.<sup>1</sup> Augite again seems to be wanting. It is possible that this may be an offshoot from the Porth-Gain mass, the last-described variety of which it much resembles.

The other intrusions, all of which seem to be narrow sills, have a totally-different character, so far as I have been able to examine them. They are distinctly more basic in composition. The feldspars have a higher refractive index than balsam, and the symmetrical extinctions of twins on the albite-type correspond to a basic oligoclase or andesine, in some cases approaching that of labradorite,  $Ab_1An_1$ . There is much pale-brown augite, more or less ophitic, and a few relics of scarcely-recognizable enstatite, although some of the rather abundant chlorite may represent it. Quartz is scarce, except where the feldspars are much decomposed, and apatite is absent or very rare. Iron-ores in the form of ilmenite, more or less altered, and pyrites occur. These rocks would be called diabase; but, as enstatite undoubtedly occurs, I am inclined to associate them both with the St. David's-Head intrusions and with the typical diabase of the Llanwnda type. It is highly probable that they represent a mixture of the two types.

I was unable to confirm the colouring on the Geological-Survey maps to the east of Trevine, as the conditions did not permit of my tracing the continuity of these sills into the Abercastle-Mathry area; on account of the unfavourable time of year, much of the country being inaccessible owing to growing crops of corn. So far as my observations went, however, these diabase-sills seem to be absent from the neighbourhood of the fault.

Ynys-y-Castell is a small islet lying off the north of Abercastle Bay, only accessible at low water. It consists of an igneous intrusion of fine grain and bluish-grey colour. In the hand-specimen this bears a close resemblance to the rock of Porth-Gain Quarry, but under the microscope it appears to be of a distinctly-basic character

<sup>1</sup> Otto Meyer, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxx (1878) p. 21; and E. Hussak, Tscheru. Min. & Petrogr. Mitth. n. s. vol. i (1878) p. 275.

the majority of the felspars being more highly refractive and the small quantity of quartz being most probably secondary. The felspars are generally too turbid for determination. Ilmenite, as usual in all the rocks described, continued to separate after the felspars. It is considerably altered to sphene, very little intermediate leucoxene remaining. Augite is present, sometimes in rather idiomorphic crystals, but in other cases penetrated by felspar-prisms. That some augite preceded felspar is proved by its occasional inclusion in the latter mineral. Rhombic pyroxene seems to have been present in considerable quantity, but is now almost entirely altered. Chlorite is abundant, and a little hornblende, associated with augite, may be secondary. Apatite is moderately abundant. There are numerous calcite-areas, and a considerable amount of fibrous secondary mineral resembling tremolite. The rock may be described as a somewhat granular type of enstatite-diabase.

I have now traced upwards, from St. David's Head to the Pwll-Strodyr Fault, a series of enstatite-bearing rocks which seem to merge into those previously described south of Strumble Head, and afford an explanation of the types of rock occurring at Llech Dafad, Tresseysilt (see Pl. XXXIX, fig. 6), Garn Bolch, and the granophyric rock of Garn Fechan.

Certain rocks of an entirely-different character, which occupy a small area west of the above-mentioned fault, in the Mathry district, remain to be described.

#### V. THE LIME-BOSTONITE AND PORPHYRITE-INTRUSIONS OF THE ABERCASTLE-MATHRY DISTRICT.

I will first call attention to the broad strip of igneous rock extending from Pwll Whiting, through Abercastle to the Pwll-Strodyr Fault. This is coloured in the Geological-Survey map as greenstone on the west of Abercastle, and as intrusive felstone on the east. It is, however, the same throughout, so far as my specimens, and examination in the field, enable me to judge. The rock is clearly intrusive, and alters the shales on the north side in the direction of the dip, that is, on its upper margin. The rock decomposes rather easily, and shows a tendency to present a vesicular appearance from the weathering-out of irregular elongated cavities formerly occupied by a dark material, resembling chloritic matter, which spots the unweathered portion of the rock. A few felspar-phenocrysts and some calcite-areas are visible. The general appearance is that of a greenish-grey trachytic rock.

Under the microscope, it is seen to consist almost entirely of felspar, chiefly in the form of laths, but some larger crystals are also present. The dark material mentioned above is seen to consist of irregular greenish patches, nearly isotropic, but often associated with a fibrous, feebly-polarizing substance resembling chlorite, and



possibly due to the hydration of an original glass, forming a kind of palagonite, in the manner suggested by Prof. Bonney in explanation of a somewhat similar occurrence in the Prescelly lavas.<sup>1</sup> Some of these patches have minute spherulites round the margin, showing a distinct cross between crossed nicols. Quartz occurs sparingly, usually in thin streaks and patches, and may be of secondary origin. Except a little granular opaque matter, probably a decomposed titaniferous iron-ore, no dark minerals are seen. Patches of calcite are visible in places, but neither these nor the other secondary material appear to replace pre-existing crystals. (See Pl. XL, fig. 1.)

The feldspars are nearly all plagioclase. The laths are rather ragged, and extinguish nearly parallel to their length. The refractive index is lower than quartz. In some cases the symmetrical extinction on each side of the trace of the twinning-plane of albite-twins reaches 10°. Flow-structure is commonly visible, and the feldspars are often bent. The porphyritic feldspars are apparently more basic than the laths.

I determined the chemical composition of this rock, selecting the least-weathered specimen obtainable, which, however, was by no means fresh. The following results were obtained :—

	Percentage.	Molecular proportions.
Silica .....	55·38	·923
Alumina .....	18·34	·181
Ferric oxide .....	1·13	·007
Ferrous oxide .....	5·86	·081
Lime .....	3·25	·058
Magnesia .....	3·47	·086
Potash.....	0·22	·002
Soda .....	7·12	·115
Titanic acid .....	0·90	·010
Phosphoric acid .....	trace	
Carbonic acid .....	2·00	
Water (at 110° Centigr.) .....	0·48	
Water (ignition) .....	2·39	
Total .....	<u>100·54</u>	

Calculating the albite- and anorthite-percentages from the soda and lime, we get

Albite.....	60·26
Anorthite .....	16·12

which would together amount to 76·38 of a plagioclase, of composition between  $Ab_4An_1$  and  $Ab_3An_1$ , corresponding to an acid oligoclase of low extinction, of which a large portion of this rock

<sup>1</sup> J. Parkinson, 'Igneous Rocks in North Pembrokeshire' Quart. Journ. Geol. Soc. vol. liii (1897) p. 468.

consists. I found its specific gravity to be 2·73. Below are given for comparison some analyses of similar rocks from other areas.

	I.	II.	III.	IV.
Silica.....	55·38	56·50	52·00	77·29
Alumina .....	18·34	18·14	18·06	14·62
Ferric oxide .....	1·13	3·12	2·18	} trace
Ferrous oxide .....	5·86	2·86	5·14	
Lime.....	3·25	3·38	4·59	trace
Magnesia .....	3·47	1·22	2·84	0·38
Potash .....	0·22	1·60	4·68	0·16
Soda .....	7·12	5·28	3·78	7·60
Titanic acid .....	0·90	0·85	0·98	n.d.
Phosphoric acid .....	trace	...	...	n.d.
Carbonic acid .....	2·00	5·11	3·59	...
Water (at 110° Centigr.) .....	0·48	1·26	1·84	0·57
Water (ignition) .....	2·39			
Manganese-oxide .....	...	...	0·25	...
	<u>100·54</u>	<u>99·32</u>	<u>99·93</u>	<u>100·62</u>

I.=Intrusive rock, Abercastle, Author's analysis.

II.=Lime-bostonite of Mæna. W. C. Brögger, 'Die Eruptivgesteine des Kristianiagebietes, III: Das Gang-Gefolge des Laurdalits' Christiania, 1898, p. 207; also 'Basic Eruptive Rocks of Gran' Quart. Journ. Geol. Soc. vol. 1 (1894) p. 26.

III.=Bostonite, Onston Ness, Orkney Is. J. S. Flett, Trans. Roy. Soc. Edin. vol. xxxix (1900) p. 873.

IV.=Keratophyre, Wicklow. F. H. Hatch, Geol. Mag. 1889, p. 72.

In some respects this rock is strongly suggestive of a bostonite. Mr. Cowper Reed's description of the smaller intrusives of Foilna-neena Cove (County Waterford),<sup>1</sup> would apply almost perfectly to the Abercastle rock. Mr. Cowper Reed was kind enough to send me a slide of the Waterford bostonite-like rock for comparison, and I find the resemblance very close. At the same time, the chemical analysis does not altogether corroborate this view, since typical bostonite not only exhibits a more completely-holocrySTALLINE structure, but has also the proportions of potash and soda approximately equal. There is, however, a very close resemblance between bostonites and certain keratophyres, and the chemical composition of the Abercastle rock is so similar to that of a rock described by Prof. Brögger as lime-bostonite from Mæna, Gran, Christiania,<sup>2</sup> that I am inclined to refer the Abercastle rock to that type. The accompanying diagram (fig. 2, p. 598) represents graphically this comparison. It is interesting to note that the lime-bostonites of Mæna are associated with a porphyritic variety, called by Brögger mænite-porphyrte: this is the oligoclase-porphyr of

<sup>1</sup> 'Igneous Rocks of the Waterford Coast' Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 677, 683.

<sup>2</sup> 'Die Eruptivgesteine des Kristianiagebietes, III: Das Gang-Gefolge des Laurdalits' Christiania, 1898, p. 207; also 'Basic Eruptive Rocks of Gran' Quart. Journ. Geol. Soc. vol. 1 (1894) pp. 23 *et seq.*

Kjerulf. Some specimens of the Abercastle rock show a similar porphyritic tendency. With the exception of the occurrence in Ireland, noted above, the only locality from which bostonite has hitherto been described in this country is in the Orkney Islands,<sup>1</sup> the analysis of which (as given by Dr. Flett), however, so far as the alkalies are concerned, differs materially from that of the Abercastle rock. It is notable that the latter rock resembles the bostonites in its marked tendency to decomposition, as is seen in the presence of a considerable proportion of carbonic acid and combined water. I have appended, for purposes of comparison, an analysis by Dr. Hatch of a keratophyre from Wicklow, which, although closely agreeing in the proportions of soda and potash, is in other respects a very different type of rock.

To the north of Abercastle, on the coast opposite Ynys-y-Castell, is another igneous exposure. From its position, this might be taken for a part of the Ynys-y-Castell diabase-intrusion. A specimen, however, taken from the top of the cliff about midway between Abercastle Bay and Porth Gwynion, looks very like a coarse agglomerate, such as is commonly seen in the Goodwick volcanic series. It contains angular greenish-grey fragments in a darker matrix. Differential weathering results in the removal of the angular fragments, leaving hollow spaces separated by walls of the more resistant matrix, a feature which may have some bearing upon the interpretation of the origin of this rock.

Under the microscope, the angular fragments are seen to consist of the bostonite-like rock, described above. The matrix is a finely-granular material, through which small bostonite-fragments are scattered. No fragments of other rocks are recognizable, and I am inclined to think that this is a brecciated, tuff-like intrusion somewhat similar to those which Messrs. Kilroe & McHenry have described in the South-East of Ireland.<sup>2</sup> Microscopic examination tends to support this view (see Pl. XL, fig. 5). The extreme angularity of the fragments, the thin shreds of uncrushed rock which occur in the matrix, and the small proportion of the matrix compared with that of the coarser fragments, tend to confirm the theory that this rock has been crushed *in situ*. If this be the case, the greater resistance of the matrix to weathering can only be explained by some secondary process which has indurated the powdered rock.

It may be noted that I found a precisely-similar brecciated rock, with the same microscopic structure (Pl. XL, fig. 6), in a small exposure at Priskilly Fawr, about 4 miles south-east of Abercastle, and not far from the Pwll-Strodyr line of fault. The exposure is very small, consisting of a patch only a few square yards in

<sup>1</sup> J. S. Flett, 'The Trap-Dykes of the Orkneys' Trans. Roy. Soc. Edin. vol. xxxix (1900) p. 873.

<sup>2</sup> 'Intrusive, Tuff-like, Igneous Rocks & Breccias in Ireland' Quart. Journ. Geol. Soc. vol. lvii (1901) p. 479.

area, protruding in a marshy field about half a mile west of the farmhouse. I believe that the rock is *in situ*, and its occurrence at this horizon would then tend to confirm its intrusive origin. It is possible that these brecciated intrusions have been produced by earth-

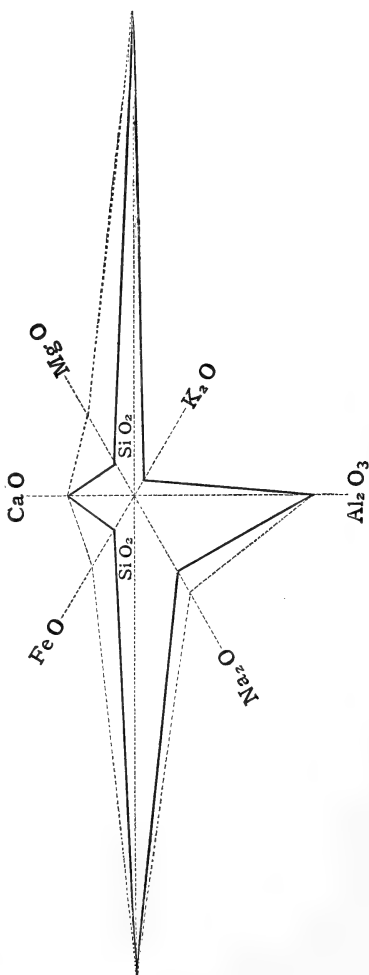
movements, in a manner somewhat similar to those described by Mr. Lamplugh in the Manx Volcanic Series,<sup>1</sup> a conclusion which is strengthened by the fact that a good deal of folding is noticeable in the cliff-sections near Abercastle.

Several of the parallel sills lying between Abercastle and Mathry are of the same type as the Pwll-Whiting-Abercastle intrusion. Specimens from Carnachen Wen (Pl. XL, fig. 2) and from an exposure in the Abercastle road, about a mile from Mathry (Pl. XL, fig. 4), are petrographically identical with the lime-bostonite of Abercastle, with the exception of a greater proportion of porphyritic feldspars. I noticed no sign of brecciation, however, in these areas.

A somewhat different type occurs at Cwm-y-Graig, near the south-eastern extremity of Mathry Hill, where a conspicuous

boss of pale-blue compact rock is quarried for road-metal. Microscopically, this rock differs from the type described above, in having

Fig. 2.---Diagram illustrating the comparison between the Abercastle rock and the lime-bostonite of Mena.



[The continuous line represents the Mena rock, and the broken line the Abercastle rock.]

<sup>1</sup> 'On some Effects of Earth-Movement on Carboniferous Volcanic Rocks of the Isle of Man' Quart. Journ. Geol. Soc. vol. lvi (1900) p. 20.

frequently a banded structure, owing to the presence of lines of opaque white spots. It has then the appearance of a banded spherulitic felsite. Under the microscope, however, these white patches are seen to be merely circular spots of incipient decomposition, the banded structure being apparently due to shearing or fluxion-structure. There is no trace of any spherulitic structure. Shearing has largely confused the original character of the rock, but it seems to belong to the same type of rock as that described above, with the exception that phenocrysts of a ferromagnesian mineral are represented to a limited degree. This is a pale pyroxene, very fibrous, and looking very much like an altered rhombic form. Some doubtful monoclinic pyroxene is seen, and the rock may, perhaps, be designated an augite- or enstatite-porphyrite. (See Pl. XL, fig. 3.) It is mapped by the officers of the Geological Survey as a contemporaneous lava. I think, however, that it is intrusive, and is a modification of the lime-bostonite series described above.

For reasons already mentioned (p. 593), I was not able to examine all the exposures in the Mathry district, but among my specimens from that area there is not a single indication of the Llanrian lava-series. The appearance rather suggests a series of thin parallel sills of lime-bostonite or porphyrite, which is the typical form that such intrusions take in some other localities. I was equally unable to trace the continuity of the enstatite-dabase sills of Trevine eastwards to the Pwll-Strodyr Fault, all my specimens from this area belonging either to the lime-bostonite type of Abercastle or to the porphyrite-type. Much remains to be done, however, in accurately mapping this area, and as the igneous exposures may belong to any of the above-described varieties (which, in the field, are not always easy to distinguish), considerable care will be necessary, not only in separating the lime-bostonites and porphyrites from the contemporaneous flows, but also in ascertaining the exact limits of the enstatite-dabase-intrusions.

It is probable, also, that other exposures of this type occur beyond the Mathry district. In the Geological-Survey collection of rock-slices from this part of Pembrokeshire are two specimens, one from the Tremynydd range, and the other from the Carn-Llidi area, which closely resemble this type; but their exact localities are not quite certain.

## VI. REVIEW OF THE PETROGRAPHY OF THE ROCK-TYPES.

Under this head attention is drawn to certain points of petrographical or mineralogical interest, which have come under observation in the examination of a large series of rocks from the areas dealt with in the foregoing pages. These I will now proceed to describe.

**Apatite.**—This mineral is a very prominent constituent of certain of the rock-types, but in others it is rare or absent. It is, for example, extremely rare in the Fishguard and Prescelly diabases, and in the more basic variety of the enstatite-diabases of the Llan-ran and Trevine areas; but in the quartz-enstatite-rocks it is often abundant, and always present to some extent. This distribution of apatite is very noticeable at Carn Llidi. The basic norite of the western extremity of this mass apparently contains no apatite, but towards the east, where the rock passes into quartz-norite, apatite becomes conspicuous. In the lime-bostonite series it seems to be wanting.

**Iron-ores.**—Magnetite seems to be confined almost entirely to some of the fine-grained rocks of Strumble Head, the dolerite of Carn Gilfach, and the fine-grained intrusions of Y Garn. In all the other types the only recognized species of iron-ore is ilmenite, often in good rhombohedral forms. The usual decomposition-products, leucoxene and sphene, are present. Pyrites is often present, but is apparently not confined to any particular groups of rock.

**Rhombic pyroxene.**—The rhombic pyroxene occurs in various forms, and exhibits very different degrees of alteration. The least-altered forms occur in some of the diabases, and show no fibrous structure. Only the pinacoidal cleavages are recognizable. These possess marked pleochroism: rays vibrating parallel to the  $\gamma$  axis are green, those vibrating parallel to the  $\beta$  axis being yellow. In no case is the brownish-red colour, characteristic of the brachy-diagonal vibrations ( $\alpha$ ) in typical hypersthene, visible. These characters would seem to point to a bronzite-variety of enstatite. Various degrees of hydration lead to the development of the fibrous forms, diacrasite and bastite, with a corresponding loss of pleochroism; while, in other cases, the mineral passes into a kind of chloritic pseudomorph. In the diorite-series the prevailing form of the enstatite is in prisms terminated at one extremity by rather rounded domes. The crystals frequently are elongated in the direction of the  $c$  axis. They are always fibrous and generally faintly pleochroic, the latter quality being sometimes confined to patches only.

Lastly, in the norite-series we find the rhombic pyroxene in broad plates, often changed to a colourless fibrous substance with high double refraction and nearly-straight extinction. This may be an amphibole.<sup>1</sup> At other times the ordinary bastite-alteration is present. All the varieties include sphene-granules.

Interesting variations occur in the order of separation of the rhombic pyroxene. In the diabases it seems always to have preceded

<sup>1</sup> This change has been noted in other cases; see O. H. Erdmannsdörffer, 'Die devonischen Eruptivgesteine & Tuffe bei Harzburg, &c.' *Jahrb. der k. Preuss. Geol. Landesanst. & Bergakad.* vol. xxv (1904) pt. i, p. 47.

augite, in which it is often included. In the other groups it is frequently intergrown with augite, and in some cases even encloses the latter mineral. Similar reversals of order with regard to feldspar may also be noticed. Sometimes it precedes the latter, and at other times is penetrated ophitically by it.

**Monoclinic pyroxene.**—In the diabases augite usually occurs in typical ophitic plates; but granular augite, tending to idiomorphic development, is not wanting in certain types—as, for example, Garn Fawr, Trellys, Llanwnda, and other localities. In the enstatite-bearing rocks idiomorphic forms are, on the whole, more common, and are often polysomatic. Twinning on the usual plan, that is, simple binary twins, the twinning-plane being parallel to the orthopinacoid, is an exceedingly-common feature of the granular augites; and the so-called sahlite-striation, parallel to the basal plane, with typical herring-bone twins, occurs usually in the norite-group. Pleochroism is not distinguishable, and the colour is generally a very pale brown.

In many of the rocks there appear to be two distinct generations of augite. In a specimen from Garn Fawr the earlier generation has a higher  $\alpha\gamma$  extinction-angle than the later form. The maximum extinction of the most ferri-ferous variety is about  $43^\circ$ .

A characteristic feature in all the rock-types is the freshness of the augite. Uralite-alteration is comparatively rare, and the polarization-tints are usually very uniform.

**Hornblende.**—The distribution of this mineral is well-defined. In the Carn-Llidi ridge it is wanting or very scarce. In the St. David's-Head ridge it begins to come in towards the east; but in the Carnedd-Ileithr Carn-Trelwyd ridge it is prominent, and it occurs also at Penberry Hill, after which it was only noticed at Ynys-y-Castell, where, however, it is present in small amount, and may be secondary. In some slides it appears as an outgrowth on augite, and seems generally to be associated with the later stages of consolidation, being more noticeable in the neighbourhood of quartz-areas. It is pale-brown in colour, with normal pleochroism.

**Biotite.**—This mineral has only been noticed in the basic norite-type of the western end of Carn Llidi and St. David's Head. It presents normal characteristics.

**Feldspars.**—The feldspars generally are not of a very basic kind, even in the diabases; but the norites appear to contain labradorite of composition  $Ab_1An_1$ . In the diabases the usual type is andesine, but in the quartz-bearing rocks there are frequently at least two generations of feldspar, the earlier being the more basic. Orthoclase is apparently present in many of the dioritic types, and is also a constituent of the micropegmatite. Albite characterizes the quartz-albite-enstatite-rock of Porth Gain, and the lime-bostonites have a

rather acid oligoclase. The twinning is normal in nearly all the specimens examined, the pericline-type, although occasionally seen, being uncommon. In a variety from Tresseysilt a somewhat unusual 'window-shaped' twinning occurs, in which four rather square parallelograms have a nearly-parallel simultaneous extinction, and are surrounded by a framework, extinguishing at  $10^{\circ}$  to its length. In the  $45^{\circ}$  position all trace of the twin-structure disappears.

The accurate determination of the feldspars in many of the rocks is rendered difficult by their turbidity.

Secondary products.—Among secondary products sphene and leucoxene are everywhere present, but call for no further notice, with the exception of the marked tendency of the enstatite-pseudomorphs to include little aggregations of sphene-granules.

Epidote is very abundant in the diabases, but is not so noticeable in the other types. Granular epidote often shows a marked tendency to develop round the margins of chlorite-areas in the gabbro- and diabase-types, and, beginning thus, gradually spreads over the whole area. In quantity, it generally bears a direct proportion to the amount of alteration exhibited by the feldspars. In the enstatite-bearing rocks, in which the feldspars are of a more acid type, this feature is not noticed, a character which agrees with Prof. Zirkel's statement that saussuritization is not usually conspicuous in the norites.<sup>1</sup> An interesting occurrence in several of the latter is that of a colourless uniaxial mineral of tetragonal form, with rather high double refraction, and rectangular cleavages. The refractive index is higher than quartz. I refer this to one of the scapolites. Prof. Judd has explained the conversion of plagioclase-feldspar into scapolite,<sup>2</sup> and it is a significant fact that the rock of Oodegaarden, Norway, in which this conversion is described, is a gabbro containing rhombic pyroxene. Similar occurrences have been noted in the diabase-dykes of Lake Champlain,<sup>3</sup> and in the diabase of the Pyrenees.<sup>4</sup> In Canada, also, Prof. F. D. Adams and Prof. A. C. Lawson have noted the occurrence of scapolite in an enstatite-diorite.<sup>5</sup> In the present case, the scapolite has been noted in a few examples only in the St. David's-Head rocks; it has all the appearance of being of secondary origin, and not, as considered by Mr. J. E. Spurr, in the case of some Alaskan rocks, a primary constituent.<sup>6</sup>

Of other secondary products chlorite is an abundant constituent of the Strumble-Head diabases, but is less prominent in the quartz-norites of the St. David's-Head district. In a few instances vermicular chlorite (helminth) is noticeable in these varieties. In the enstatite-diabases there is evidence of a gradual passage of

<sup>1</sup> 'Lehrbuch der Petrographie' 2nd ed. vol. ii (1894) p. 776.

<sup>2</sup> Min. Mag. vol. viii (1888-89) p. 186.

<sup>3</sup> J. F. Kemp & V. F. Marsters, Bull. U.S. Geol. Surv. no. 107 (1893).

<sup>4</sup> A. Lacroix, Comptes Rendus Acad. Sci. Paris, vol. cx (1890) p. 1011.

<sup>5</sup> 'On some Canadian Rocks containing Scapolite, &c.' Canad. Rec. Sci. vol. iii (1888-89) p. 185.

<sup>6</sup> 'Scapolite-Rocks from Alaska' Am. Journ. Sci. ser. 4, vol. x (1900) p. 310.



enstatite into chlorite, and examples occur in which the chlorite-patches contain nuclei of enstatite. The chloritic substance in the lime-bostonites has already been mentioned.

Less frequently are found brightly-polarizing, radially-aggregated zeolitic species. Sericite and opaque amorphous granular matter are common alteration-products of the feldspars in the southern area. I noticed also that the Llanwnda type develops asbestiform shear-planes locally, a phenomenon which I never observed in the rocks between St. Nicholas and St. David's Head.

## VII. MUTUAL RELATIONS OF THE MAGMAS.

I have endeavoured to show that there is evidence in this area of three distinct types of intrusion, namely: (1) the gabbro-type, including the diabase of Fishguard and Prescelly, which I have designated the Llanwnda type; (2) the norite and enstatite-diorite type of St. David's Head; and (3) the lime-bostonite type of the Abercastle-Mathry district. We may consider what evidence there is as to the age of these intrusions, and whether they may be regarded as the result of differentiation from an original magma or the product of distinct intrusions from different deep-seated sources. Prof. Brögger's explanation of the origin of the bostonites and camptonites of Gran,<sup>1</sup> which he regards as complementary dykes resulting from the differentiation of an olivine-gabbro-diabase magma, can scarcely be applied to the present case, in the absence of a larger series of chemical analyses. In the case of the lime-bostonite series of Abercastle, however, the evidence seems to point to the conclusion that these are of earlier date and quite distinct from either of the other types. In the first place, they were evidently intruded before the main faulting of the district took place, since these narrow sills are abruptly truncated by the Pwll-Strodyr Fault. Moreover, they are sharply distinguished from any other intrusions in this area, and do not show, so far as I have observed, any gradual passage into, or admixture with, either the quartz-norites on the one hand, or the diabase-group on the other. Mr. Cowper Reed brings forward evidence to show that the Waterford intrusions are later than the first post-Ordovician folding and earlier than the pre-Upper Old-Red-Sandstone denudation.<sup>2</sup> Messrs. Kilroe & McHenry assign the intrusive tuff-like rocks of the south-eastern corner of Ireland to the Old-Red-Sandstone age.<sup>3</sup> The evidence for these conclusions seems to be fairly complete. I have no acquaintance with the Waterford district personally, but the lime-bostonites and porphyrites of Abercastle so strongly resemble some of these Irish

<sup>1</sup> 'Basic Eruptive Rocks of Gran' *Quart. Journ. Geol. Soc.* vol. 1 (1894) p. 26.

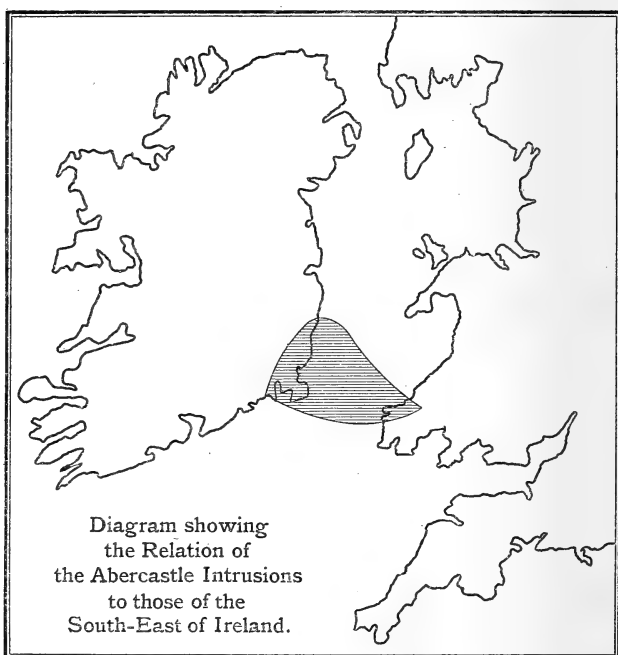
<sup>2</sup> 'Igneous Rocks of the Coast of County Waterford' *Quart. Journ. Geol. Soc.* vol. lvi (1900) p. 690.

<sup>3</sup> 'Intrusive, Tuff-like, Igneous Rocks & Breccias in Ireland' *Quart. Journ. Geol. Soc.* vol. lvii (1901) p. 488.

intrusions, that it seems reasonable to refer them to the same period. It is, at least, certain that they are earlier than the period during which the Pwll-Strodyr faulting took place.

In the case of the quartz-norite intrusions the evidence is more obscure. I have not been able to find any section in which they are actually seen in contact with the lime-bostonite sills. At Ynys-y-Castell they occur very near together, and here the lime-bostonite is brecciated and tuff-like. It may, therefore, perhaps be inferred that the brecciation is connected with the later intrusion of the Ynys-y-Castell rock, although such an explanation does not necessarily hold

Fig. 3.



in the case of the similar brecciation at Priskilly Fawr. It is perhaps more probable that the brecciation in each case is connected with the period of faulting, the exposures lying comparatively near to the line of the Pwll-Strodyr displacement. My evidence as to the relation of the Pwll-Strodyr Fault to the quartz-norite intrusions is admittedly imperfect; but, so far as it goes, it seems to support the view that the quartz-norites were intruded later than the main period of faulting. This view is supported by the apparent absence of any signs of brecciation or shearing in any of the rocks of this type which have come under my notice. With some hesitation, therefore, I ascribe the quartz-norites to a later period than the lime-bostonites.

Coming next to the diabase-series, we have evidence that the Garn-Fawr Y-Garn intrusions are of a composite nature; and it appears to be certain that, between Strumble Head and St. David's Head, there is an indefinite zone of enstatite-diabases, which seem to graduate south-westward into the quartz-norite rocks, and north-eastward into the Strumble-Head diabases, as if some amount of mixing of two magmas had taken place locally. This seems to be a sufficient explanation of the marked change which the gabbro-diabase magma of the Fishguard area undergoes as it approaches the norite-region, and, as mentioned above (p. 583), is quite in accordance with the experimental results obtained by Prof. Vogt. This phenomenon is noticeable around Trevine, in the St. Nicholas area, and at Y Garn and Garn Bolch. Of course, such a result might equally be expected to occur in the case of a deep-seated magmatic differentiation, as explained by Prof. Brögger; but in either case it would imply an approximately-contemporaneous origin for these two types. There is need, however, of more detailed work on the Garn-Fawr Y-Garn complex before its structure can be properly understood.

In the absence, therefore, of further evidence, I assume that at a later period than that at which the lime-bostonites were intruded, the strata were injected with more or less contemporaneous laccolitic intrusions of a diabase-magma from the Fishguard area, a norite-magma from the St. David's area, and a mixed magma over an ill-defined intermediate zone. It might be possible to generalize further, and to assume some connection between the enstatite-bearing rocks of this district with those of other localities, such as those of the Breidden Hills,<sup>1</sup> Carrock Fell,<sup>2</sup> Penmaenmawr,<sup>3</sup> and the Whin Sill<sup>4</sup>; but in the present state of our knowledge such a conclusion would be merely speculative.

With respect to evidences of differentiation *in situ*, I am convinced that a more detailed examination of this area will afford interesting results, which, however, are beyond the scope of my present researches.

### VIII. SUMMARY AND CONCLUSIONS.

The observations recorded in the foregoing pages point to the following conclusions:—

1. The contemporaneous lavas of the Llanrian area agree generally in character with the eruptive rocks of apparently-Ordovician age in the Strumble-Head and Prescelly districts. These are all of an essentially-acid type.

<sup>1</sup> W. W. Watts, Quart. Journ. Geol. Soc. vol. xli (1885) pp. 539 *et seqq.*

<sup>2</sup> A. Harker, Quart. Journ. Geol. Soc. vol. l (1894) p. 317.

<sup>3</sup> *Id.*, 'Bala Volcanic Series of Caernarvonshire' 1889, pp. 62 *et seqq.*

<sup>4</sup> J. J. H. Teall, Quart. Journ. Geol. Soc. vol. xl (1884) pp. 640 *et seqq.*

2. The intrusive rocks are of later date, and are of three distinct types, namely:
  - (a) The gabbros and diabases of the Strumble-Head area.
  - (b) The norites and associated rocks of St. David's Head and the surrounding district.
  - (c) The lime-bostonites and porphyrites of the Abercastle-Mathry district.
3. The lime-bostonite series is apparently older than the gabbros and norites, and seems to belong to the petrographical province of the South-East of Ireland.
4. The gabbros and norites were intruded approximately during the same interval, at a later period.
5. The norites and associated rocks have spread north-eastward from St. David's Head, and have penetrated the area of the Strumble-Head intrusions.
6. The gabbros and diabases have similarly spread to a limited extent south-westward into the norite-area.
7. The gabbro- and norite-provinces are separated by an ill-defined zone, in which some mixture of the magmas took place.
8. The latest phase of igneous activity was the formation of the Pen-Caer basaltic laccolite, with apophyses penetrating the Garn-Fawr Y-Garn intrusions.

It is not, of course, necessary to assume that each of the several intrusions was confined to any one single stage of vulcanicity. The laccolites and bosses were probably the result of injections, extending over a prolonged interval, from co-existing magma-basins or from a single differentiated magma. There are clear evidences of some further differentiation *in situ*, but the full extent to which this took place offers a large field for future investigation.

In conclusion, I have to express my indebtedness to Mr. G. T. Holloway for placing his laboratory at my disposal, and thus greatly facilitating the chemical work connected with the preparation of this paper.

## EXPLANATION OF PLATES XXXVIII-XL.

### PLATE XXXVIII.

Geological sketch-map of the country between Fishguard and St. David's Head, on the scale of  $1\frac{1}{2}$  miles to the inch.

### PLATE XXXIX.

- Fig. 1. Biotite-norite from the western end of Carn Llidi, showing 'herring-bone' twin of augite. The minerals represented are plagioclase, augite, rhombic pyroxene, and ilmenite.  $\times 30$  diams. (See p. 585.)
2. The same rock, showing large plates of rhombic pyroxene enclosing plagioclase and intergrown with augite.  $\times 30$  diams. (See p. 585.)
  3. Quartz-norite, Penberry Hill, with conspicuous bronzite. The feldspars are cloudy, and the augite is granular.  $\times 30$  diams. (See p. 588.)
  4. Albite-enstatite rock, Porth-Gain Quarry. The enstatite is much altered, and is interstitial to the feldspar.  $\times 30$  diams. (See p. 592.)
  5. Enstatite-diorite, with micropegmatite, Carnedd Lleithr.  $\times 30$  diams. (See p. 587.)

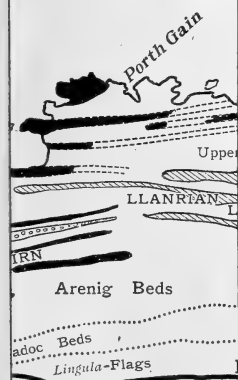
# MAP

## 'S HEAD.

*nile and Porphyrite*

*rian Lava-Flows*

*mporaneous Tuffs, etc.*



Pre-Ca

EN ANGLÂS

IW

GOODWICK

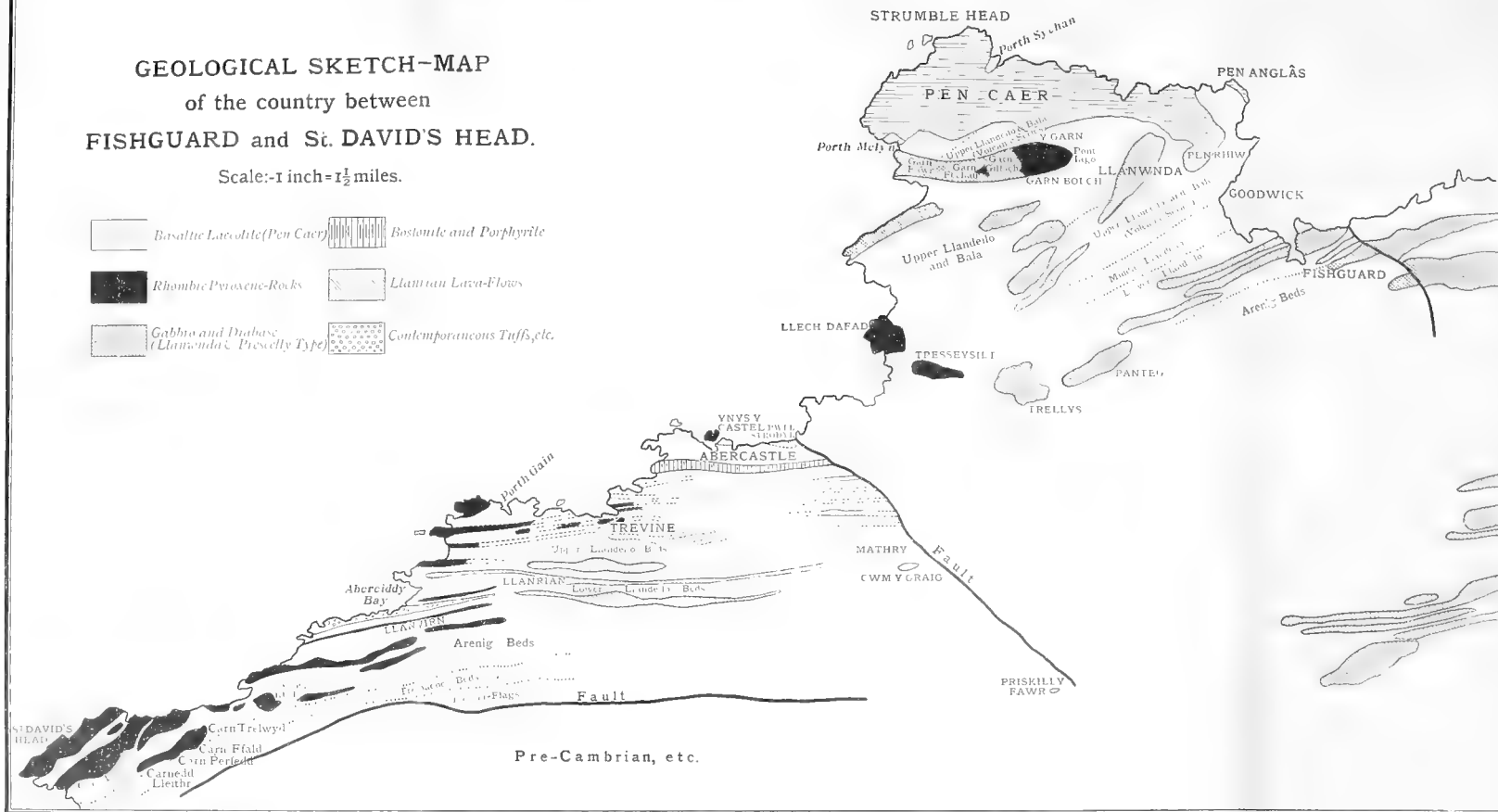
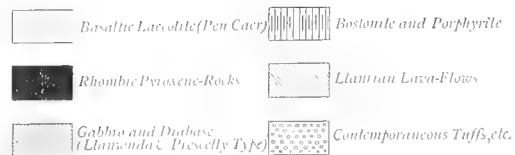
FISHGUARD

Arenig Beds

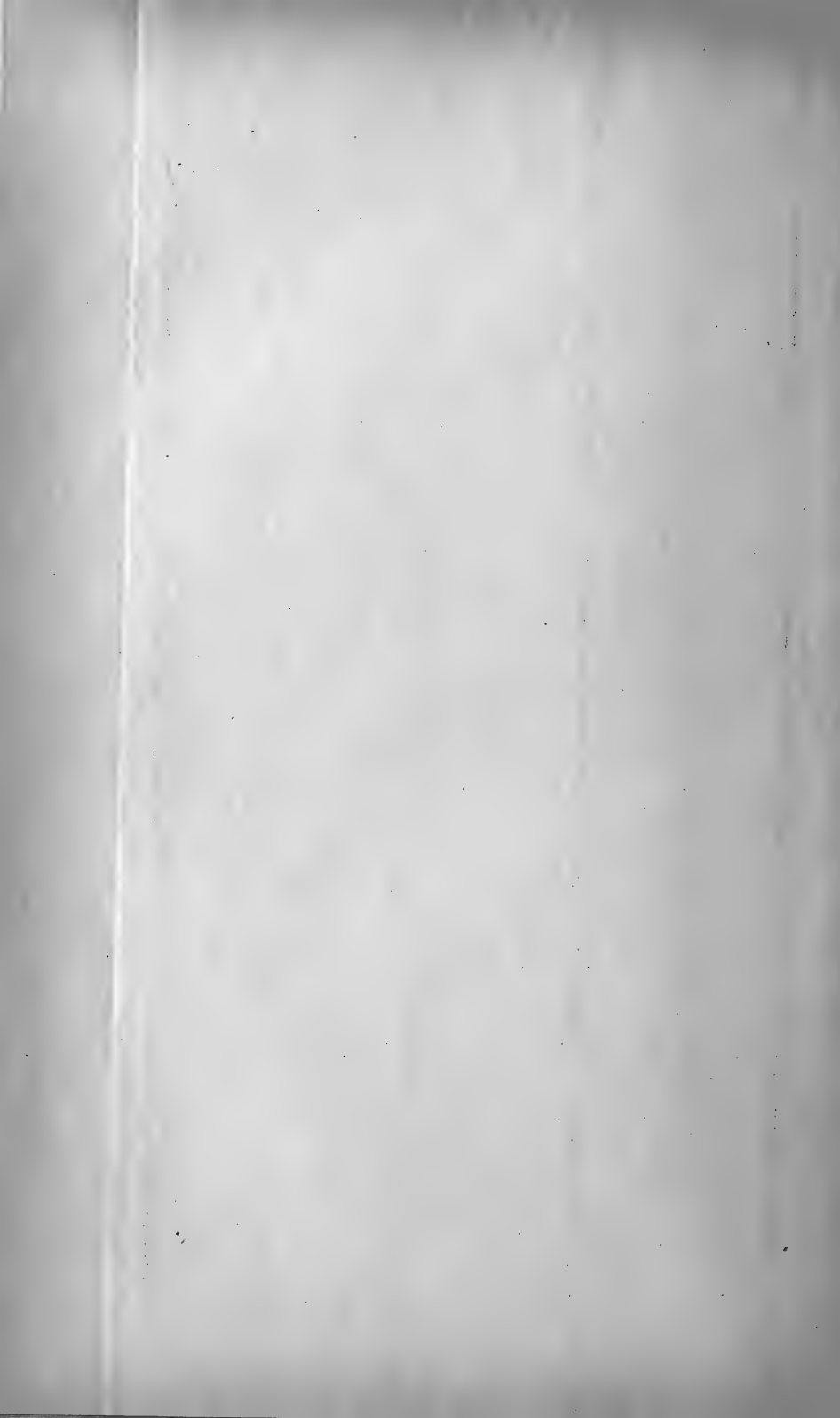


# GEOLOGICAL SKETCH-MAP of the country between FISHGUARD and St. DAVID'S HEAD.

Scale: 1 inch = 1½ miles.



[For 'Ynys y Castel' read 'Ynys y Castell.']





1



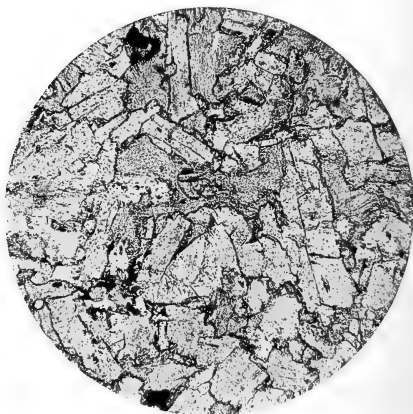
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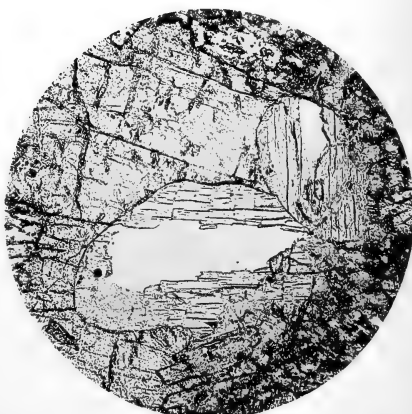
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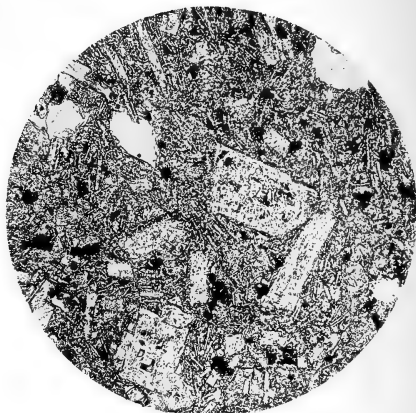
NORITES AND OTHER ENSTATITE-ROCKS FROM PEMBROKESHIRE.



1



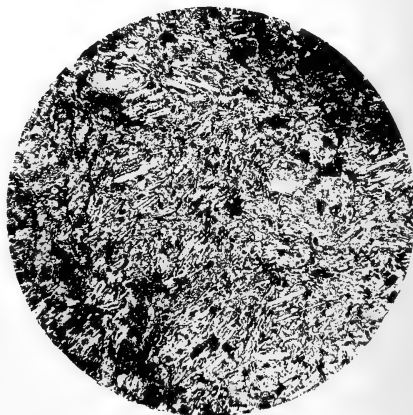
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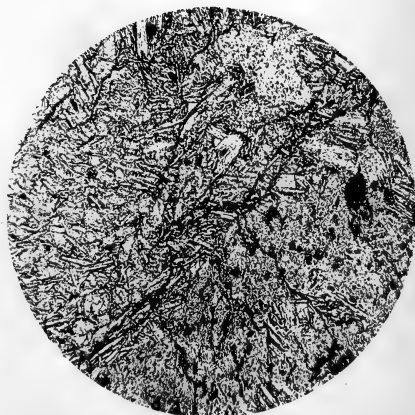
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5



6



LIME-BOSTONITES AND PORPHYRITES FROM PEMBROKESHIRE.



Fig. 6. Enstatite-diabase, Tresseysilt, near St. Nicholas. Two crystals of almost unaltered enstatite are seen enclosed in augite. The crystals are similarly oriented, and, lying nearly at right angles one to the other, show simultaneously two axial colours with the single nicol.  $\times 30$  diams. [The clear spaces in this figure are merely holes in the rock-slice.] (See p. 594.)

#### PLATE XL.

- Fig. 1. Lime-bostonite, from Long House, near Abercastle.  $\times 30$  diams. (See pp. 594-95.)
2. Oligoclase-porphyrity, from Carnachen Wen, near Abercastle.  $\times 30$  diams. (See p. 598.)
3. Pyroxene-porphyrity, Cwm-y-Graig, near Mathry. The large crystal has the appearance of a rhombic pyroxene.  $\times 30$  diams. (See pp. 598-99.)
4. Lime-bostonite, 1 mile north of Mathry.  $\times 20$  diams. (See p. 598.)
5. Brecciated lime-bostonite, from the cliff north of Abercastle.  $\times 30$  diams. (See p. 597.)
6. Brecciated lime-bostonite, from Priskilly Fawr, 3 miles south-east of Mathry.  $\times 30$  diams. (See p. 597.)

#### DISCUSSION.

Prof. WATTS referred to the fact that the Author had dealt with the igneous rocks associated with the Ordovician in greater detail than hitherto. Many of the Author's types seemed to occur in Shropshire and Montgomeryshire. He wished to know whether the Author had succeeded in ascertaining the age of the intrusive rocks. The sudden transitions between gabbro and diabase observed in this district were also to be seen in Shropshire, and even in Skye.

Prof. JUDD congratulated the Author upon the accomplishment of a very valuable piece of detailed petrographical work. He stated that a parallel for the apparently-capricious association of fine-grained and coarse-grained varieties of rock remarked upon by the Author could be found in many intrusive masses.

Mr. J. LOMAS joined in the congratulations which had been accorded to the Author, and agreed with Prof. Watts that rocks of similar types were found in the Berwyn Hills and other parts of North Wales. He further asked whether any of these rocks were really undoubted interbedded lavas, as work in North Wales had tended to show that many rocks mapped as such were intrusive.

The AUTHOR said, in reply, that he was not able to bring forward any evidence as to the precise age of these intrusions, but those of the South-East of Ireland appeared to agree generally in time with those of the Breidden Hills. With regard to the sudden and apparently-irregular transition from rocks of coarse to those of finer grain, this seemed to point to the conclusion that the size of crystals was determined by various factors and not alone by the rate of cooling. As to contemporaneous igneous rocks, the Llanrian acidic lavas were obviously of this nature; but whether these Llanrian sheets were continued to the east into the Mathry district, he could not definitely state. He thanked the Fellows present for the manner in which his communication had been received.

29. *On the GEOLOGY of ARENIG FAWR and MOEL LLYFNANT.* By WILLIAM GEORGE FEARNSIDES, M.A., F.G.S., Fellow of Sidney Sussex College, Cambridge. (Read January 18th, 1905.)

[PLATE XLI—MAP.]

# I. INTRODUCTION.

THE mountains known as Arenig Fawr and Moel Llyfnant are situated somewhat to the north of the centre of the county of Merioneth, and lie immediately east of the main water-parting of Wales. The area studied lies wholly within the quarter-sheets 13 S.E., 13 S.W., 21 N.E., & 21 N.W. of the 6-inch Ordnance-Survey maps of Merionethshire. Rising from a plateau some 800 to 1200 feet high, they attain heights of 2800 and 2437 feet respectively, and, being entirely above the cultivation-zone, are practically uninhabited. The Great Western Bala-Ffestiniog Railway crosses the northern end of the district, to which Arenig Station, close under the northern slopes of Arenig Fawr, affords easy access.

Although to a certain extent glaciated, the mountains are swept clean rather than Drift-covered, and it is only in the lower ground that moraines become inconveniently abundant. The adaptation of surface-forms to rock-structures is exceedingly complete, and few are the places where the ribs of harder rocks do not protrude through the scanty soil or turf. Being open to the full blast of the westerly and south-westerly gales from the ocean, the district receives its full share of weather; and, in consequence, although the eastern slopes are often grass- or heather-covered, the steeper parts of the western slopes are rugged and bare, and afford magnificent exposures of the component rocks. Further, the structure of the district is fairly simple, and the cleavage, though present, is not so strongly developed as to prevent one from breaking the rock along the bedding-planes.

Ever since the time when Sedgwick applied the name of Arenig Ashes and Porphyries to the lower series of North Welsh volcanic rocks, the Arenig district has been a source of interest to geologists. Yet, and notwithstanding that the name of Arenig is so constantly upon the lips of all who study or teach the geology of the Lower Palæozoic rocks, no complete or detailed account of it has yet been published.

The only connected general account of the district which I have found, is that contained in the first edition of Sir Andrew Ramsay's 'Geology of North Wales.'<sup>1</sup> A good deal of additional information is contained in the second edition of that work (1881), but is somehow

<sup>1</sup> Mem. Geol. Surv. vol. iii (1866)

less easy to extract. Much more instructive are the few pages devoted by Messrs. A. V. Jennings & G. J. Williams<sup>1</sup> to the Garth Grit, and the recent paper by Miss G. L. Elles<sup>2</sup> on the general palæontology of the Arenig rocks of Wales.

Passing now from printed matter, I take this opportunity of acknowledging my indebtedness to Prof. T. McKenny Hughes. F.R.S., and also to Mr. G. J. Williams, F.G.S., H.M. Assistant-Inspector of Metalliferous Mines, of Bangor. Prof. Hughes has, in the course of the last twenty years, made frequent excursions to Arenig, alone and also as leader of large classes of Cambridge students. He has in this way collected a vast amount of extremely useful material, and all this, together with the corresponding field-notes and sketch-maps, he most generously placed at my disposal.

Mr. G. J. Williams was long resident at Ffestiniog, which is only about a dozen miles away, and more than twenty years ago discovered the fascinations of the Arenig district as a collecting-ground. Unfortunately, change of residence and increased pressure of work have latterly prevented him from continuing his researches, which have never been concluded; and when I announced my intention of mapping the whole country on the 6-inch scale, he kindly gave me a day over the ground, pointing out fossil-localities. Moreover, since that time he has always allowed me full access to his fine and carefully-localized collection of Welsh fossils.

## II. DESCRIPTION OF THE ROCK-SUCCESSION.

The general succession (see also figs. 1 & 2, pp. 610-11) of the sedimentary rocks of the district is as follows:—

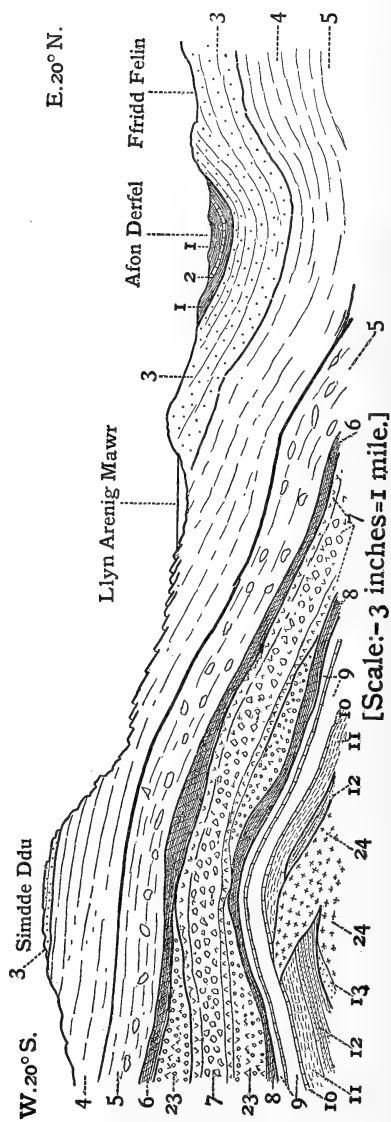
ORDOVICIAN.	{	<i>Dicranograptus</i> -Shales.	}	Caradoc.					
		Derfel or <i>Orthis</i> -Limestone.							
		Rhyolitic Ashes = Upper		Upper Ashes of	Llandeilo.				
		Massive Ashes = Middle				Arenig.			
		Acid Andesitic Ashes = Lower							
		Daerfawr Shales. Zone of <i>Didymograptus Murchisoni</i> .		Lower (Hypersthene-Andesites)		Arenig.			
		Platy Ashes.							
		Great Agglomerate.							
		Olechfa or <i>Bifidus</i> -Shales. Zone of <i>Didymograptus bifidus</i> .		Zone of <i>Didymograptus</i>			Arenig.		
		Filltirgerig or <i>Hirundo</i> -Beds.						<i>hirundo</i> .	
		Erwent or <i>Ogygia</i> -Limestone.							
		Henllan or <i>Calymene</i> -Ashes.						Zone of <i>Didymograptus</i>	
		Llyfnant or <i>Extensus</i> -Flags.							<i>extensus</i> .
		Basal Grit.							

Unconformity.

<sup>1</sup> 'Manod & the Moelwyns' Quart. Journ. Geol. Soc. vol. xlvii (1891) pp. 373-74.

<sup>2</sup> Geol. Mag. 1904, pp. 199-211.

Fig. 1.—Section across the northern shoulder and eastern slopes of Arenig Fawr.



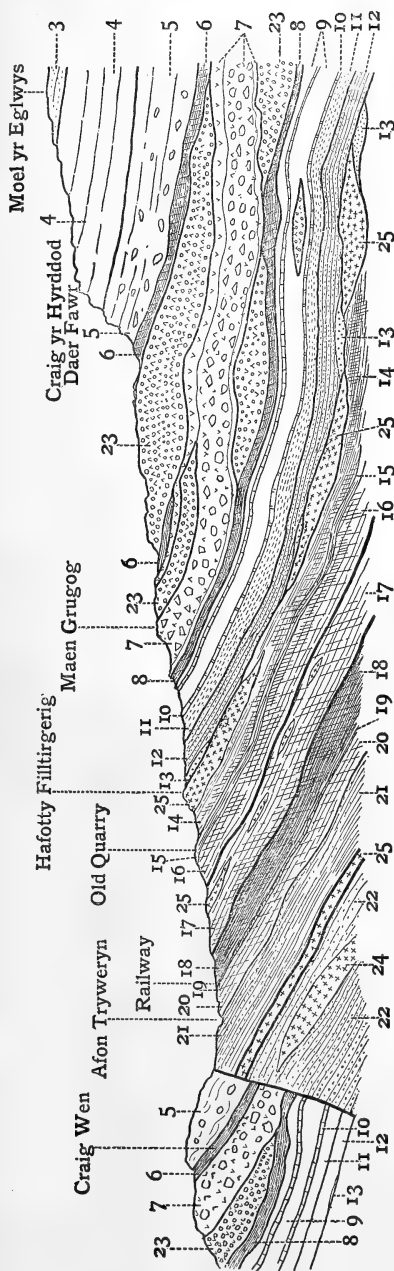
[For explanation, see fig. 2, below.]



Fig. 2.—Section across the western flanks to the summit of Arenig Fawr.

N.W.

S.E.



[Scale:- 3 inches = 1 mile.]

- |   |   |   |
|---|---|---|
| 1 = <i>Dicranograptus</i> -Shales.          | 9 = Filtirgerig Beds with Ash-Band.                           | 17 = <i>Niole</i> -Beds.                      |
| 2 = Dertel Limestone.                       | 10 = Erwent Limestone.  | 18 = <i>Peltura</i> -Beds.                    |
| 3 = Rhyolitic Ashes.                        | 11 = Henllan Calcareous Ashes.                                | 19 = <i>Orthis-lenticularis</i> Band.         |
| 4 = Massive Ashes.                          | 12 = Llyfiant Flags.  | 20 = <i>Parabolina</i> -Beds.                 |
| 5 = Acid Andestic Ashes.                    | 13 = Basal Grit.  | 21 = <i>Lingulella</i> -Beds.                 |
| 6 = Daerfawr Shales.                        | 14 = Amodd Shales.  | 22 = Grits and flags of the Ffestiniog Beds.  |
| 7 = Lower Ashes and Agglomerates of Arenig. | 15 = Tai-Herion Flags.  | 23 = Intrusions of Hypersthene-Andesite.      |
| 8 = Olchfa Shales.                          | 16 = Nant-ddu Beds, with <i>Dicryonema</i> -Band at the base. | 24 = Intrusions of Ophitic Andestic Dolerite. |
|   |   | 25 = Intrusions of Hornblende-Porphyrte, etc. |

CAMBRIAN.	{	Annodd or <i>Shumardia</i> -Shales.	}	Tremadoc.	
		Tai-Herion or <i>Asaphellus</i> -Flags.			
		Nant-ddu or <i>Bellerophon</i> -Beds.			
		<i>Dictyonema</i> -Band.			
		<i>Niobe</i> - and <i>Psilocephalus</i> -Beds.			
	{	<i>Peltura</i> -Beds.	} Black Band.	Dolgelly.	
		<i>Orthis-lenticularis</i> Band.			
		<i>Parabolina</i> -Beds.			
		<i>Lingulella</i> -Beds.			} Ffestiniog.
		Grits and Flags.			

There are also important intrusions of andesites (almost identical with the Lower Ashes of Arenig), hornblende-porphyrates, and ophitic dolerites.

### The Ffestiniog Beds [22].

The oldest rocks of the district occur in the west and south-west, and belong to the shallow-water phase of the *Lingula*-Flags. They are a monotonous series of grits and flags with hardly any fossils, and determine a belt of most uninteresting, boggy, heather-covered, rolling moorland of only slight relief. Westward they rise to form the steep escarpment which locally determines the main watershed of Wales. Although usually dipping eastward or north-eastward at about 30°, they are so broken up by folds and faults of small amplitude, that, in the absence of any continuous exposure, it is impossible to form any exact estimate of their thickness; but, as the outcrop is considerably more than a mile wide, that thickness must be considerable.

The beds are best exposed in the valley of the Lliw, where also may be seen a fine large sill of hornblende-porphyrite, quite like the well-known sills which occur at about the same horizon at Dolgelly.

### The *Lingulella*-Beds [21].

Towards the top these grits and flags become much finer in texture, and in the highest 30 or 40 feet are crowded with specimens of *Lingulella Davisii*, McCoy, which, in places, become so abundant as to form the greater part of certain bands (4637).<sup>1</sup> These beds are exceedingly easy to recognize by their mode of weathering, for, from being bluish-grey, they become first quite rusty and brown and then increasingly paler, until finally they are almost white. A similar belt of fossiliferous flags occurs in the same relative position at Penmorfa (Portmadoc) and at Rhobell Fawr; hence it would seem that the division should be traceable all round the Harlech dome. The beds are well exposed in the two westernmost branches of the Trinant Valley.

### The *Parabolina*-Beds [20].

Passing upward, the *Lingulella*-Beds become finer-grained and less gritty, giving place gradually to the hard flaggy shales of the

<sup>1</sup> The numerals in parentheses throughout the text of this paper refer to the numbers of the corresponding rock-specimens preserved in the Sedgwick Museum at Cambridge.

*Parabolina*-Beds. These are dark bluish-grey, and give a sonorous ring when struck; they break with a curious, china-like, conchoidal fracture, and tend to fly before the hammer. They contain a certain amount of iron-pyrites, and coat themselves with yellow rust in the early stages of weathering, although this afterwards disappears and the whole rock appears much darker.

In the lower parts they are quite unfossiliferous, but about the middle certain bedding-planes yield indifferently-preserved examples of *Parabolina spinulosa*, Wahl., which becomes abundant in the higher beds.

### The *Orthis-lenticularis* Band [19].

Some 200 feet from the base of the *Parabolina*-Beds appears a band of darker and more earthy shale crowded with innumerable shells of *Orthis lenticularis*, Dalm. This band is only some 4 or 5 feet thick, but is readily recognized at intervals all round the Harlech dome from Ogof-ddu near Criccieth to Dolgelly. It is best seen in the old Nant-y-Derbiniaid slate-quarry, immediately north-west of the area mapped, but is also very evident in the western Trinant-stream section, about 100 yards south of the confluence with the eastern tributary. In both these places the *Orthis* is abundant enough to render the shale quite calcareous.

### The *Peltura*-Beds [18].

Above the *Orthis-lenticularis* Band begins the famous 'Black Band,' distinguishable from all other beds in the district by the fact that when it is scratched with a hammer the streak produced is quite black. The coming-in of the black coloration is of course gradual, and, with practice, one can tell by the streak exactly with what bed one is dealing. Many have thought that the blackness of the beds is due to graphite or organic matter; but a study of the way in which the rock rusts in weathering leads me to think that it is rather due to the presence of finely-divided, slightly-decomposing iron-sulphides. When heated alone, the slates become slightly paler, and acids, which will dissolve iron-pyrites but have no action on graphite, completely bleach small pieces of it.

The sediment composing the Black Band is finer than that of either the beds below or above it, and accordingly has, in places, taken on sufficient cleavage to tempt some persons to open trial-holes for slate. The slates obtained are very soft and silky, but they rust and scale at so early a stage in the weathering that, although easy to work, they have not proved to possess any permanent value, and all the trials are now abandoned. The best-cleaved material contains abundant distorted fragments of *Peltura scarabaeoides*, Wahl., and fine, large examples of *Agnostus trisectus*, Salt., are not uncommon. The lower layers near the *Orthis*-Band yield occasionally *Sphaerophthalmus alatus*, Böeck, and one or two specimens of *Ctenopyge pecten*, Salt., have also been found there.

The best exposure in the district is the stream-section in the lower part of the Trinant Valley; but that in the small stream which comes down from Moel Llynant to the Bedy-uchaf of Hendre Blaen-lliw is also quite good. The Drift south of Tai Herion, too, affords a good collecting-ground, and the specimens of *Peltura* which it contains in abundance are the only evidence for the completion of the *Lingula*-Flag succession to the east of the great North-and-South Fault.

### The *Niobe*-Beds [17].

Towards the top the beds of the Black Band lose their silky character, and become cleaved mudstones rather than slates. *Peltura* is no longer abundant, but occasional examples of *Niobe Homfrayi*, Salt., and *Psilocephalus innotatus*, Salt., take its place. Passing up, the amount of pyrites rapidly diminishes, and through dark-blue the sediments assume a rather light leaden-grey colour. Weathered and joint-surfaces are no longer thickly coated with scaly rust, but are merely filmed over with it, and often appear iridescent.

The character of the sediment also alters, and the main mass of the *Niobe*-Beds is not unlike that of the lower part of the *Parabolina*-Beds. The jointing, however, is quite different, and is rather like that of the well-known 'needle-slate' rocks of Portmadoc, which belong to the same horizon. Judging from casual specimens, obtained from washouts in the heather-covered moorland, the *Niobe*-Beds must occupy a good deal of ground on the north and west of Moel Llynant, but exposures are not encouraging. The best exposure is undoubtedly the stream-section along the eastern branch of the Trinant Valley, which runs along the strike of these beds for more than half a mile. This section well shows the relation between the beds and a series of sill-like intrusions of granular andesite or dolerite, which characterize this horizon right across the district. Similar beds and intrusions are well seen in the old road-section west of Nant-ddu, in the railway-cutting north of Y Waun, which is east of the great North-and-South Fault, and again for about a mile to the west and north-west of Hendre Blaen-lliw.

### The *Dictyonema*-Band [16 pars].

Overlying the *Niobe*-Beds is the *Dictyonema*-Band, which (most unfortunately) is even more imperfectly exposed than they are. *Dictyonema* has been found abundantly in certain small boulders in the Drift of the Tryweryn Valley and elsewhere, but is only seen *in situ* at one locality. Fortunately this spot, a few yards west of Nant-ddu, adjoins one of the few sections from which *Niobe* has been obtained, and it is perfectly clear that there, as ever in the Portmadoc district, the *Dictyonema*-Band overlies the *Niobe*-Beds, and has nothing whatever to do with the Black Band below. On this evidence, I would class the Welsh

*Dictyonema*-Band as the lowest division of the Tremadoc, and would place the *Niobe*-Beds as the highest member of the Dolgelly or Upper *Lingula*-Flags. Wherever found, *Dictyonema* is always enclosed in dark bluish-grey shale, which on inside joints is invariably filmed over with iridescent iron-oxide; also, it is always associated with spicules of some sponge like *Protospongia*. As above mentioned, the only good exposure of the *Dictyonema*-Band is the Old-Road section, a few yards west of Nant-ddu; but sponge-spicules *in situ* and *Dictyonema* in a loose block have been found close to the mountain-fence, about half a mile due west of the summit of Moel Llyfnant. The thickness of the band is quite small, and, as at Penmorfa, cannot much exceed 15 or 20 feet.

### The Nant-ddu or *Bellerophon*-Beds [16 *pars*].

Above the *Dictyonema*-Band is the most monotonous and uninteresting series in the district. This, in the absence of any more characteristic fossil, I have termed the *Bellerophon*-Beds. It consists of a series of hard, rather dark-grey, gritty shales, usually exhibiting a certain amount of incipient needle-cleavage; and, in the upper part, where the beds become softer, it has often been prospected for slates. At certain horizons the shales become quite calcareous, and flattened concretions of cone-in-cone chalybite up to a foot or two in diameter are almost characteristic (4638). The lower part of the series has yielded no trilobites, but occasionally contains a few oval *Lingulæ*, *Acrotreta*, and frequent, rather distorted, undeterminable *Bellerophons*. The best exposure is in the banks of the stream of Nant-ddu, and the entrance-cutting to the old manganese-mine which was worked in these beds there. *Bellerophons* are most abundant in the Afon Amnodd-bwll, about a quarter of a mile south of Yr Orsedd. A small trial-hole for slate, opened in higher beds close under the overlying Tai-Herion Flags in Nant Rhos-ddu, yields also examples of a broad form of *Asaphellus Homfrayi*, Salt., and a few distorted specimens of *Olenus* (*Parabolinella*) *triarthrus*, Call., and *O. (P.) Salteri*, Call., which suggest a correlation with the lower fossiliferous horizon of Belswardine Brook, Sheinton (Shinerton).

### The Tai-Herion or *Asaphellus*-Flags [15].

Immediately above these fossiliferous slates come the much coarser and more quartzose beds, to which I have applied the name of Tai-Herion or *Asaphellus*-Flags. These are a well-marked series of hard, blue, shaly or slaty calcareous flags, and contain numerous worm-tracks and castings filled with white quartz-sand (4639). Certain beds among them also show remarkably well a rather curious form of ripple-bedding. In these 'ripple-bedded' rocks, alternations of coarser and finer sediment take place laterally as well as vertically; and the rock appears

to be built up of flattened lenses of the coarser, closely set in a matrix of the finer material. Such rock, when compelled to break along the bedding, affords surfaces which are either nodular, or crossed somewhat irregularly by ripples of short wavelength. Curiously enough, such ripples always appear to have a trend which is almost parallel to the strike of the bedding-planes, which here makes a considerable angle with that of the cleavage.

Apart from the ripple-bedding, the *Asaphellus*-Flags are much more massive than any of the other divisions of the Tremadoc; and this character has so enabled them to withstand the agents of denudation, that they stand up as a visible feature right across the district. The same property has also caused them to be considerably quarried for wall-building by the makers of the roads. Fossils are not superabundant, but a good many very large specimens of *Asaphellus Homfrayi*, Salt., of broad type have been found in the alternations of the coarse and fine layers of the ripple-bedded flags; and it is noticeable that all such specimens are found with the dorsal side upwards, and are filled with coarser and covered by finer material. One or two enrolled specimens have been found, and these too are filled with coarse, and embedded in fine, material.

The best and most accessible exposure is that afforded by the road-side quarry immediately west of the Nant-Rhosddu bridge at Tai Herion. The waterfall just below that bridge is determined by the same beds, and the old quarries west of the Amnodd-wen road, near Hafotty Filltgerig, are in similar though slightly-higher beds. Other sections are also seen at Yr Orsedd, and a curious piece of folding below Ceunant-y-gareg-ddu allows them to appear as inliers in the gorge there. The sections west of Moel Llyfnant are not so satisfactory, and have not proved to be very fossiliferous. The whole series is not more than 80 or 100 feet thick. It appears to correspond with the gritty shales of Penmorfa Post-Office, although unfortunately no *Dikelocephalus* has as yet been obtained here.

### The Amnodd or *Shumardia*-Shales [14].

Above the *Asaphellus*-Flags the beds gradually become much softer, and pass into a series of fossiliferous blue-grey mudstones. Except when baked by the intrusive dolerite-sills, which are common at this horizon, these beds are much softer than any of the other beds of the district; and so they usually occur in hollows and boggy places in the moors. Though sheared and considerably distorted, they rarely show any definite cleavage. Close to the dolerite-sills they are often much hardened, but break readily along a series of close-set quadrangular joints. In such places certain beds take on a very characteristic concretionary or shrinkage-jointing, and weather out into a mass of ovoidal lumps and curved splinters rather after the fashion of a massive basalt. When such concretions are broken across during the process of weathering, one finds the successive rings beautifully and differentially iron-stained,

after the manner of the Moughton Whetstones of Yorkshire. Fossils are, as a rule, fairly abundant, the most characteristic of them being the beautiful little *Shumardia*. Slabs with ten or a dozen specimens of *Asaphellus Homfrayi*, Salt. (of narrow type) are not uncommon, and *Agnostus Siedenbladhi*, Linn., and *Macrocyrtella Mariae*, Call., may also be obtained from most exposures.

The fauna obtained is as follows:—

*Asaphellus Homfrayi*, Salt.  
*Shumardia salopiensis* (Call.), cf.  
*elandica*, Moberg.  
*Ogygia* (*Niobe*) *scutatrix*, Salt.  
*Olenus* (*Parabolinella*) *triarthrus*, Call.  
*Agnostus Siedenbladhi*, Linn.  
*Symphesurus Croftii*, Call.  
*Remopleurides*.  
*Holometopus*.

*Dikelocephalus*.  
*Cheirurus*.  
*Conularia Homfrayi*, Salt.  
*Theca operculata*, Salt.  
*Bellerophon multistriatus*, Salt.  
*Ctenodonta*.  
*Lingula* cf. *Nicholsoni*, Call.  
*Acrotreta* (*Obolella*) *Sabrinæ*, Call.  
*Protospongia*-spicules.

There are also abundant, branching, carbonaceous markings which are often regular enough to suggest graptolites, but are not sufficiently well preserved for identification.

The best localities and collecting-grounds are the east-and-west stream-sections south of Amnodd-wen and north of Amnodd-bwll respectively. The latter is particularly good, and has yielded the best specimens of *Shumardia* and many beautiful slabs of *Macrocyrtella Mariae*, Call. The gorge known as Ceunant-y-gareg-ddu presents an excellent exposure of the lowest beds, and has yielded examples of all the fossils recorded, except *Remopleurides*. *Remopleurides*, indeed, seems to be exceedingly rare, and is only represented by Mr. Williams's one specimen, which came from Amnodd-wen. The best *Asaphellus*-slabs were obtained from the bed of the stream, which crosses the road about 250 yards south of Hafotty Filltirgerig.

As will be seen from the foregoing list, the *Shumardia*-Shales may be exactly correlated with the main fossiliferous horizon of Sheinton, and with beds overlying the Post-Office Flags at Penmorfa. The highest *Shumardia*-Beds of the latter locality, which are there exceedingly prolific, do not seem to be represented here, and the overlying *Angelina*-Beds are almost certainly absent, probably by reason of the succeeding unconformity.

Here, then, ends the series which British geologists are in the habit of calling Cambrian, and, in leaving it, I would remark upon the exact correspondence between each of the divisions and its homotaxial equivalent at Portmadoc. Each fossiliferous band, each change in the character of the sediment, can be recognized; and, although the total thickness must be greater at Arenig than at Tremadoc, I think that the difference is due rather to subsequent packing by earth-movement than to diversity in original deposition.

Above the *Shumardia*-Beds, *Asaphellus*-Flags, or *Bellerophon*-Beds, is a surface of unconformity. This is not a great dis-

cordance marking the uprise, wane, and degradation of some huge continental mountain-chain, but an unconformity and surface of overlap produced by the passing of some early Caledonian earth-wave, which has left but little permanent impress upon the dip and strike of the rocks which it affected. So slight was the disturbance, that the district mapped is almost too small to permit of proving it; and one might hammer and map for many days on end, without discovering any discordance at all. It was only by following the line of Mr. Williams's Garth Grit for several miles to the west, that I was able to make up my mind as to the importance of the unconformity. In that direction, the grit rests successively upon all members of the Tremadoc Series, and at the Nant-y-Derbiniaid slate-quarry comes into the Black Band or *Peltura*-Beds of the Dolgelly, or Upper *Lingula*-Flags. Further excursions along the same line suggest that the various members of the Lower Ordovician Series overlap each other westward against the surface of unconformity; and the knowledge that the similar grit at Ty-obry, Minffordd (Portmadoc), is directly overlain by shales belonging to the zone of *Didymograptus Murchisoni*, Beck, lends credence to such a supposition.

### The Basal Grit of the Arenig Series [13].

Upon the unconformity rests a grit, notable for its inconstancy of thickness and variability in character. Sometimes it may be as much as 50 to 100 feet thick, but usually it thins off rapidly, and may entirely die out in something less than 150 yards. Occasionally it is clean and white, and from the abundance of disseminated vein-quartz may become almost a quartzite. More commonly it is rather impure, and has much ashy material among it. Usually it is a fairly-coarse, even-grained grit; but sometimes, especially when thickest, its middle part becomes almost conglomeratic. In all cases, the constituent grains are rounded rather than angular. Grains of hyaline quartz are fairly common, but pebbles directly derivable from the underlying Tremadoc or Dolgelly Beds are conspicuous by their absence. Under the microscope, it is seen that the grit is a good deal sheared, and that grains usually show well-developed strain-shadows and suture-cracks. The quartz-cement is in crystalline continuity with the adjoining grains, the original outlines of which are often almost obliterated (4640). A certain amount of carbonate-cement (chalybite?) is also present, and patches of rather fresh andesine or oligoclase are not rare (4641). No newly-formed minerals were observed.

The best exposures are the patches mapped on the northern flanks of Moel Llyfnant and adjoining the dolerite-intrusion south of Llechwedd Erwent; but the grit is more easily visited at the patch east of Waen-goch on the way to Amnodd-wen, or that along the Ffestiniog road at Llechwedd Deiliog.



The Llyfnant or *Extensus*-Flags [12].

Upon the Basement Grit or surface of unconformity, as the case may be, comes a distinctly-defined series of well-bedded blue-and-white quartzose flags. These flags are remarkably resistant to the weathering processes, wherefore they determine a prominent feature right across the district, and, being well jointed, give rise to the beautiful stepped or terraced scenery which is so well seen on the eastern flanks of Moel Llyfnant. They are remarkably well bedded, and, being provided with convenient shaly or micaceous partings, split readily into fine large slabs. In former days these were quarried for flags and hearthstones, which were much sought after down at Bala. Under the microscope the bedding becomes even more apparent, and it is seen that calcite and shreds of detrital mica make up quite as large a proportion of the finer bands as do the actual quartz-grains. There is also a great deal of unresolvable muddy paste and some secondary quartz. The quartz-grains are much more angular than those of the underlying grit, and are often also curiously ragged at the edges (4642).

Although so flaggy, the Llyfnant Beds are yet quite fossiliferous, and certain of their bands have yielded very numerous graptolites of the extensiform type. The most abundant form is *Didymograptus deflexus*, E. & W., but *Didymograptus extensus*, Hall, is not rare, and Mr. Williams has also specimens of *Loganograptus Loganii*, and a *Tetragraptus* which is probably *Amii*. Tails of some large *Ogygia* have also been found, and worm-tracks and castings (both small and great) are extremely abundant. The markedly-flaggy beds are from 150 to 200 feet thick.

The best collecting-ground is afforded by the old quarries south of Hafotty Filltirgerig, or by the stream-section which adjoins them. The general character of the beds, however, is better shown in the precipitous north-eastern face of Moel Llyfnant, or in the more shelving slopes of Llechwedd Erwent.

The Henllan or *Calymene*-Ashes [11].

Passing upwards, the well-bedded character of the Llyfnant Flags gradually disappears, and, as the sediment does not become correspondingly finer, the succeeding beds assume a notably 'blocky' character. With this they also take on a toughness which defies description, and, although well-jointed on a small scale, appear to retain neither bedding nor cleavage. Their colour is grey, and they are granular and conchoidal in fracture, and in weathering become covered with a characteristic, thick, cream-white crust. They are more calcareous than the underlying flags, and contain much less detrital quartz and practically no mica (4643). They appear to be derived from some more or less distant volcanic source, which, judging by the thickening and increase of ashy material southwards, probably lay in that direction, and provided materials richer in lime (and therefore more basic) than any of the products of the later volcanoes of the district.

They are not abundantly fossiliferous, but yield occasional large and rather well-preserved specimens of *Calymene*, probably *C. parvifrons*, Salt., which appear only during the later stages of weathering. With these also occur a few large gasteropods, such as *Raphistoma* or *Maclurea*; and many indeterminable *Orthoceratidae*, including a possible *Endoceras*.

In order to prevent confusion with the underlying beds, the local name is taken from the western slopes of Craig Henllan. There, unfortunately, the exposures are far from good, and much better collecting-ground is afforded by the higher northern slopes of Moel Llynant. The structures and general relations are also well exhibited a short distance south of Ceunant-goch and all along the slopes of Llechwedd Erwent.

### The Erwent or *Ogygia*-Limestone [10].

Towards the top the *Calymene*-Ashes become mixed with a considerable proportion of shaly material, which, being arranged in thin lenticles not more than an inch or two long, gives the rock a streaky-bacon-like appearance. The rock is still very hard and tough, but is now sufficiently calcareous to become porous and breakable when weathered, and in such conditions usually yields quite good casts of shelly fossils. The matrix of the rock still includes much of the basic ash characteristic of the *Calymene*-Ashes below, but has in addition a good many chips of that acid plagioclase which is so characteristic of higher beds (4644). The most abundant trilobite is now *Ogygia Selwynii* (Salt.), which must sometimes have attained a length of 8 or 9 inches, although more frequently it is represented by specimens only 2 or 2½ inches long, or by numerous tails not more than half an inch across. Tails of this species are much more abundant than heads, and nearly all the moderately-complete specimens are more or less enrolled. *Calymene parvifrons*, Salt., is still fairly abundant, and specimens up to 4 inches long have been found. An *Ampyx* (possibly *A. Salteri*, but very like *A. domatus*, Linn.) is abundant at certain exposures. Of other fossils an *Orthis* like *Carausii*, Salt., or *calligramma*, Dalm., is characteristic of the lower, and *Obolella plumbea*, Salt., of the upper, part of the series. *Orthoceras* is everywhere, and many-branching dendroid graptolites are occasionally met with in the shaly layers. The entire fauna obtained is as follows:—

*Ogygia Selwynii*, Salt.  
*Calymene parvifrons*, Salt.  
*Ampyx Salteri* (?) or *domatus*, Linn.  
*Orthoceras encrinale*, Salt.  
*Orthoceras sericeum*, Salt.  
*Orthoceras* sp.  
*Raphistoma*.  
*Maclurea*.

*Bellerophon*.  
*Palæarca*.  
*Ctenodonta*.  
*Orthis calligramma*, Dalm.  
*Orthis Carausii*, Salt.  
*Obolella plumbea*, Salt.  
*Lingula Rouaulti*, Salt.  
*Callograptus radiatus*? (Hopk.).

It is noticeable that the whole aspect of this fauna, its general composition and numerical proportion of forms, is exceedingly

suggestive of the *Nesuretus*-Beds of South Wales. The fossiliferous character of these beds has long been known, and it was from them, at localities north and south-east of Tai Herion, that the officers of the Geological Survey obtained all their truly-Arenig specimens. A better collecting-ground is afforded by the slopes of Llechwedd Erwent, and by those between that hill and Foel Boeth. The highly-fossiliferous band is not more than 10 or 12 feet thick, but is rendered very evident by the streaky character of the rock. The outcrop of the belt runs roughly parallel to the contours of the hill, from the northern dolerite-intrusion of Llechwedd Erwent to the pass which goes over to the Llafar Valley, and then turns southward following round the slopes of Foel Boeth, and is fossiliferous all the way.

### The Filltirgerig or *Hirundo*-Beds [9].

Becoming still more streaky, the Erwent Beds pass gradually, and finally rather suddenly, into the dark, blocky, calcareous shales of the *Hirundo*-Beds. These, too, are as a rule slightly ashy, and in the upper part include one or two well-defined bands of tuff. In the main, however, they are of detrital origin, and contain a great deal of remarkably-angular chips of quartz, together with some very well-preserved flakes and shreds of colourless mica (4645). The more shaly beds are well bedded, and show rapid alternations of sandy, shaly, and micaceous material, as in the corresponding beds of Pont Seiont. Fossils are not especially abundant, but graptolites, where found, are usually preserved in pyrites and stand out in full relief. In shaly beds *Didymograptus hirundo*, Salt., is most frequent, and with it small forms referred to *D. nitidus*, Hall, or *D. patulus*, Hall, have been found. There are also a good many ill-preserved Tetragraptids, including *Tetragraptus serra*, Brongn., and *T. reclinatus*, Elles & Wood; and a single example of *Didymograptus gibberulus*, Nich., has been found. These are associated with imperfect fragments of Asaphid trilobites and of *Æglina*. In the very streaky beds at the base of the series *Obolella plumbea*, Salt., continues to be abundant, and with it has been found a fine slab of *Azygograptus suecicus*, Thg.

When traced across the district these beds undergo considerable variation. In the south the streaky character is more or less constant throughout the series, but in the north the middle part becomes less calcareous and more shaly, and at the top there appear two well-defined ash-beds, which in the extreme north attain a thickness of quite 20 feet. Under the microscope it is seen that these ashes agree in composition with the andesites of the main Lower Volcanic Series of Arenig (4646 & 4647). The lower band contains numerous well-rounded grains of quartz and certain 'nummulite'-like pebbles of friable shale which agree exactly in character with the masses described by Prof. Grenville A. J. Cole<sup>1</sup> as occurring

<sup>1</sup> Geol. Mag. 1890, p. 449.

in the basal Ordovician Grit of Rhobell Fawr. The upper band of ash is thinner but even more gritty; and it must, I think, have been the character of this rock which led Miss Elles<sup>1</sup> to conclude that the *Hirundo*-Beds at Nant Rhos-ddu rest unconformably upon Tremadoc rocks, and to record ashes as occurring in the latter group. Above the higher ash the beds are again very blocky, and so calcareous that they were termed limestones by Miss Elles, who obtained *Didymograptus hirundo*, Salt., from the layer directly above the ash-band. In general, the *Hirundo*-Beds are much softer than the Erwent Beds below, or than the volcanic group which covers them with screes from above. Exposures are correspondingly unsatisfactory, and it was only where a small landslip had bared a scar on the slope of Maen Grugog, close to Filtirgerig, that I was able to see the main mass of the shales *in situ*. Fortunately, in that same area the trend of the glaciation coincides for some distance with the outcrop of the beds, which have therefore provided a moderate proportion of the smaller boulders in the adjoining Drift, and over all the slopes above Filtirgerig examples of *Didymograptus hirundo*, Salt., may be occasionally found in the Drift. A very good place to search is the Drift exposed in the banks of the Nant Filtirgerig, immediately above the waterfall. The ash-bands and higher beds are best seen in the Nant-Rhos-ddu section, but are also easily made out where they cross the Hafotty-Filtirgerig stream. The well-known mass of *Ampyx*-bearing streaky beds there exposed is probably a fallen block or transplanted boulder, and is quite out of place.

### The Olchfa or *Bifidus*-Shales [8].

Upwards the *Hirundo*-fauna seems to die out suddenly, and within a foot of the bed in which the last *Didymograptus hirundo* was collected, quite a selection of species belonging to the *Bifidus*-fauna may be found. Correspondingly the sediments lose their calcareous character, but this variation is gradual; and were it not that the *Bifidus*-Beds are pyritous instead of calcareous, the two would be indeed difficult to distinguish. Here, however, fossils come to our aid, and are so abundant that even poor exposures will usually yield determinable graptolites.

Under the microscope it is seen that the *Bifidus*-Shales are far finer in texture than those of the *Hirundo*-group, but they also contain chips of detrital quartz and shreds of mica which are much too coarse for the rest of the materials. The slide also shows many ragged flakes of what is probably graphite, together with the more usual pyrites (4648).

The *Bifidus*-Beds, like the soft shales of the *Shumardia*-group, never seem to be properly cleaved, and, although distorted, the rock always breaks along the bedding-planes, which, under the microscope, appear slightly puckered. The fauna obtained is the typical

<sup>1</sup> Geol. Mag. 1904, p. 207.

Lower Llanvirn fauna of the late Dr. Hicks, but is without the *Placoparia* and other trilobites common in South Wales. The *Bifidus*-Beds are most unusually thin, but in their 20 or 30 feet bear record of a very notable evolution of graptolite-life. Near the base the commonest species is *Didymograptus nanus*, Lapw., together with *D. patulus*, Hall, *Cryptograptus tricornis*, Carr., a *Dendrograptus*, and *Didymograptus bifidus*, Hall, of the normal small type. At the top, the vaguely-defined *Diplograptus dentatus*, Brongn., which probably includes several species, is most abundant, and with it are *Didymograptus artus*, E. & W., *D. acutidens*, Lapw., *D. stabilis*, E. & W., *Glossograptus* sp. and *Cryptograptus tricornis*, Carr., and many specimens of *Didymograptus bifidus*, Hall, of a type intermediate between *D. bifidus* and *D. Murchisoni*. At this horizon also tails and other fragments of some *Ogygia*, like *O. peltata*, Salt., or possibly *O. Buchii*, Brongn., are not infrequent, and a *Dionide* closely similar to those from Ty-obry has been observed.

Like the *Hirundo*-Beds below, the *Bifidus*-Beds are not well exposed. Coming, however, immediately beneath the great volcanic group, they have been traced more or less continuously all along their outcrop. In the moorland between the Ffestiniog Road and Nant-yr-Olechfa, they appear upon their dip-slope and occupy a considerable area. Where they just cross the burn the higher beds are exceedingly fossiliferous, and the Drift of the whole area teems with fossils. Under the slopes of Maen Grugog by Filltirgerig they are again well seen, and yield a profitable return of the lower graptolites. The Nant-Rhos-ddu section has been carefully described by Miss Elles.<sup>1</sup> There the whole series is seen to be much mixed with pyroclastic felspar, and includes also some bombs of ash, a fact of considerable interest in determining the age and focus of origin of the overlying volcanic group.

### The Volcanic Series.

Upon the *Bifidus*-Shales come the earliest members of the great volcanic group of Arenig, the Ashes and Porphyries of Sedgwick. This is a series of very great thickness, but, owing to the almost complete absence of fossils, it can only be subdivided by complete field-mapping, according to the petrological character of its component rocks.

### The Lower Ashes and Agglomerates [7].

The earliest of the eruptive products of Arenig is an inconstant series of coarse, well-bedded and platy ashes. These, in the course of some 30 feet or less, pass almost imperceptibly into the massive agglomerate which forms the great bulk of the Lower Series. In places, the Lower Platy Ashes seem to thin out, and especially in the neighbourhood of certain of the contemporaneous intrusions to be described hereafter (pp. 628-30), the Agglomerate comes to rest directly upon the shales beneath.

<sup>1</sup> Geol. Mag. 1904, pp. 205-207.

The great bulk of both the Platy Ashes and the Agglomerate consists of shattered blocks and particles of a hypersthene-andesite exactly similar to that of the intrusions to be described hereafter. The blocks of the Agglomerate are set in a matrix of smaller particles of the same material, and the whole mass is usually to a considerable extent secondarily silicified (4649-51). Most of the blocks in the Agglomerate are about the size of a hen's egg or of a cricket-ball, but sometimes quite large masses are seen. With these there are also, especially in the northern district, various large and small masses of crushed and hardened, but uncleaved, shale, and in one of these several nice specimens of *Lingulella Davisii* were found. They came from a shale-mass several feet long, which occurred in the Agglomerate about 100 yards to the west of Rhyd-y-fen. Small pieces of a coarse granophyre, with patches of centrically-arranged quartz-orthoclase eutectic, and idiomorphic oligoclase, have been found in the lower part of the Agglomerate, and are interesting as being unlike any of the other rocks of the district (4652).

Masses of some ophitic rock, rather like the later dolerites, occur in the higher part of the series. The whole of the Agglomerate is exceedingly massive, and might well belong to a single phase of deposition. It is much thicker in the north and east than in the south, and particularly the south-west, where, though traceable on Moel Llynant, it appears to be rapidly dying out. Upwards the Agglomerate passes into the Upper Platy Ashes, which are similar in every respect to those below and equally uninteresting. The thickness of the Agglomerate about Clogwyn Maen Grugog must be something between 300 and 400 feet; that of the Upper Platy Ashes may be anything up to about 150 feet, and seems to be greatest where the Agglomerate is thinning, as to the east of Craig-y-Bychan.

### The Daerfawr Shales [6].

Upwards the Upper Platy Ashes become continuously finer, until they merge into the peculiar series of pyroclastic mudstones to which I have applied Mr. Williams's name, the Daerfawr Shales. These are a most variable series of deposits, and are more inconstant in thickness than even the Basal Grit. Though chemically almost pure eruptive rocks they are often beautifully laminated, and seem admirably adapted for the preservation of fossils. Where thin, they are often quite well-cleaved, and have been prospected for slates in numerous localities. Where thick, they appear uncleaved, and include certain sandy beds, with a certain amount of angular chips of detrital quartz and a few mica-plates. In such beds worm- and crustacean-tracks are quite abundant, and it was from these that Prof. Hughes obtained the problematical *Saccocaris major* and *Saccocaris minor*. Some of the beds show very fine examples of infiltrated iron or other colour-staining, which seems to be later than the incipient cleavage and jointing, through the cracks of which it has often

come. The forms taken by this colour-staining are most fantastic, and in strata with the bedding-planes undisturbed may show what appears to be a most advanced type of folding or overfaulting. A characteristic mass of pisolitic iron-ore, like those of Tremadoc and Cader Idris, appears along a crush-belt in these shales, and is exposed in the western branch of the Filttirgerig stream, south of Maen Grugog, but the field-evidence is not sufficient to show whether the mass is really a contemporaneous bed or a fault-rock deposit.

Of fossils, *Diplograptus foliaceus*, Murch., var., *Diplograptus angustifolius*, Hall, and *Dicellograptus moffatensis*, Carr., are the only species definitely identifiable. Unfortunately, although these strongly suggest the higher part of the zone of *Didymograptus Murchisoni*, they only make us long for more, and do not definitely determine the horizon. With them occur several forms of *Dicranograptus* and *Climacograptus*, also a small species of lamelli-branch and a very small *Obolella*.

The upper part of the series is again mixed with coarse ashy material, and the passage into the Upper Ashes is quite gradual.

The distribution of the Daerfawr Shales on the map is most curious. In part, at least, this is due to the great variations in thickness mentioned above, and may, therefore, depend to some extent upon the irregularities of the original surface of deposition. Largely, however, it is determined by peculiarities of surface-contour, and by the adjustment cross-folds which affected the rigid beds above and below it during the production of the cleavage of the district. The Daerfawr Shales are usually well-exposed. Good sections are afforded all along the base of the Daerfawr precipice. Fossils have been obtained immediately west of Clogwyn-y-Fran, close to Arenig Railway-station, all along the screes under Craig-yr-Hyddod, and on the south side of the Amnodd-wen Fault, where the shales are finely colour-banded. The great spread of Y Merdd is not well exposed.

### The Upper Ashes of Arenig.

The Upper Ashes are not sufficiently fresh to be of surpassing petrological interest. They are the most resistant rocks in the whole series, and determine all the higher summits, precipices, and climbing-ground in the neighbourhood. Dipping with the other rocks gently to the eastward, they have a very wide outcrop along the eastern slopes of the hills, and at first sight appear to be much thicker than they really are. Lower, Middle, and Upper divisions have been tentatively distinguished in the mapping, but there are no very sudden changes in character of the material, and what may appear to be good mappable lines at one place usually lapse into a maze of similarities within a very few hundred yards along the outcrop.

### The Lower or Andesitic Ashes of the Upper Series [5].

As above remarked, the Upper Daerfawr Shales merge imperceptibly into the Lowest Ashes of the Upper Series. This division is more basic than the rest of the series, and generally includes rather abundant shale-fragments. It is often agglomeratic (4672-73) and well bedded, and may include several thin lava-flows, but none of these extend over any considerable area. In general, it is less resistant than the Middle or Massive Series, and, being well jointed, usually forms the steep faces of cliffs and precipices which are capped by that series.

### The Middle or Massive Ashes of the Upper Series [4].

The Middle division of the Upper Series consists of ashes, which are, on the whole, much finer and more altered than those either above or below. They are, however, almost devoid of bedding, and, being jointed on an extremely-large scale, weather out into very massive and imposing forms. In the upper part they have taken on a sort of incipient cleavage-jointing, and consequently often determine rough and almost pinnacular crags. In lower ground they weather most curiously to a greenish cream-coloured rock, with abundant streaks and irregular veins of some pale chloritic mineral which suggests pinitite. Concurrently with this form of alteration there seems to be a great tendency to segregation and oxidation of the manganese which is present throughout the rock, and in former days manganese was worked, or prospected for, at frequent intervals all over the outcrop. The manganese obtained was in the form of botryoidal pyrolusite, and it is always said that the ore invariably dies out in depth. Chemically the rocks of this series are intermediate between the acid andesites of the Lower, and the basic rhyolites of the Upper, group. They are closely similar to many of the felsites and felsitic ashes of Snowdonia.

### The Upper or Rhyolitic Ashes of the Upper Series [3].

The Upper division is even more vaguely defined than the others. It consists of ashes more distinctly bedded than those below, and its members usually contain recognizable chips of felspar-crystals. The highest members of the series become so well bedded that they appear almost like massive flags in their weathering. The lower part of this Upper division, and, to some extent, the upper part of the Middle also are frequently almost impregnated with ramifying quartz-veins. In other places apparently-similar beds have been silicified along irregular veins, until they appear like cherts or adinoles (4674). For a long time I was unable to understand the nature of the alteration; a series of silica-determinations, however, at once set the matter at rest, and showed conclusively that in the more basic members of the Ash Series chert-like veins take the place of the quartz-veins of the acid members. The same series of



analyses showed me that, while the lower members of the Ashes of the Upper Series contain only about 63 per cent. of silica, the higher members may contain as much as 72 per cent.

### The Derfel or *Orthis*-Limestone [2].

Although so thick and so continuous, the Upper Ashes of Arenig end off quite suddenly, and through the massive flaggy ash of the top of the Upper division pass into a few feet of slightly-ashy shale which in turn gives place to a richly-fossiliferous brachiopod, monticuliporoid, and cystoid limestone. From the fine exposure in the gorge below the waterfall at Pont Aberderfel, I have called this the Derfel Limestone. It should be considered rather as the basal member of the succeeding belt of black shales than as a member of the volcanic group, for, although intensely pyritous, it contains practically no ashy material. When I first met with it in the valley above Pont Aberderfel I was inclined to think of it as a Drift-carried or faulted-in mass of Bala Limestone, but further work has shown that this is impossible. When traced southward, the Limestone, which in the Derfel gorge is 3 feet thick, seems to die out, and beyond Pistyl Gwyn, where it is 1 foot thick, has not been found. Northward, however, it thickens, and is readily mappable along the Valley of the Gelyn, as also about the Trausnant farm in the Valley of the Serw, and north of Arenig Fach. The fossils obtained by the officers of the Geological Survey at 'Garn, east of Arenig,' also seem to come from the same horizon cropping out east of Gylehedd. In all these places the limestone rests close down upon the highest volcanic beds, and there can be little doubt that it is conformable with them.

The fauna hitherto obtained is as follows:—

*Trinucleus concentricus*, Eaton.  
*Lichas laxatus*, M'Coy.  
*Phacops bimucronata*? (Murch.).  
*Cybele verrucosa*? (Dalm.).  
*Acidaspis*.  
*Illænus*.  
*Calymene*.  
*Harpides*.  
*Raphistoma æqualis*, Salt.  
*Clitambonites ascendens*, Pander.  
*Orthis Atonia*, Sow.  
*Orthis (Platystrophia) biforata*, Schlot-  
 heim.  
*Orthis calligramma*, Dalm.  
*Orthis (Dalmanella) elegantula*, Dalm.  
*Orthis plicata*, Sow.  
*Orthis sarmentosa*, M'Coy.  
*Orthis (Dalmanella) testudinaria*, Dalm.

*Orthis (Dalmanella) unguis*, Sow.  
*Leptæna rhomboidalis*, Welch.  
*Plectambonites quinquecosta*, M'Coy.  
*Plectambonites sericea*, Sow.  
*Plectambonites transversalis*, Dahl.  
*Triplesia insularis*, Eichw.  
*Triplesia spiriferoides*, M'Coy.  
*Strophomena antiqua*, Sow.  
*Strophomena expansa*, Sow.  
*Orthis pecten*, Linn.  
*Glyptocrinus basalis*, M'Coy.  
*Monticulipora lycoptodon*, Hall.  
*Monticulipora fibrosa*, Goldf.  
*Ischadites micropora*, Hall.  
*Ptilodictya dichotoma*, Portl.  
*Ptilodictya explanata*, M'Coy.  
*Ptilodictya fucoides*, M'Coy.

What the exact horizon of this fauna is I am unable to make out, for all the brachiopods, which are the sole really-common well-preserved fossils, belong to species with very long ranges, and might

come from anywhere between the Llandeilo and the Bala Limestones. The specimens, however, are smaller than is usual at the latter horizon, and forms transitional between pairs of related species are more frequent than forms distinctly referable to those species. The trilobites are not so abundant, and are but rarely well-preserved. Those identifiable are indicative of the higher part of the Lower or of the Middle Caradoc horizon. On the whole, the fauna seems more closely related to that of the various calcareous grits of the East-Shropshire Caradoc Series than to any single series with which I am acquainted; but, in comparing it with those faunas, it is noteworthy that all such large Orthids as *Orthis flabellulum*, *O. vespertilio*, etc. are as yet undiscovered. The commonest fossils in the limestone are a rather small form of *Orthis biforata*, Schloth., *O. Actoniae*, Sow., *O. testudinaria*, Dalm., and *Plectambonites sericea*, Sow. Monticuliporoids, bryozoa, and stems and ossicles of crinoids or cystoids are also exceedingly abundant, and make up a very large proportion of the rock.

### The *Dicranograptus*-Shales [1].

I have not seriously worked out the beds above the limestone, but what I have seen of them does not encourage me to continue. They are an enormous series of soft black shales or slates, with a varying degree of cleavage. They are beautifully exposed along the Nant Hir and other streams which flow down from the dip-slopes of the Upper Ashes to Bala Lake, along clean sections 3 miles or more in length; but, although I have passed along these daily for several weeks, I have never been able to note a single outstanding feature which would reveal to me the dip-strike or bedding of the rocks, and, except for some ill-preserved Hartfell *Dicranograptidæ* in Drift-boulders, I have never seen so much as a fossil in them.

### The Intrusions.

The intrusions of the district belong to two main and two subsidiary petrological types, and must be referred to, at least, two quite distinct periods of eruption. Each occurs in sills spreading along the bedding rather than as dykes, and all are remarkable for the way in which they hold to some fairly-definite stratigraphical, or possibly hydrostatic, horizon right across the district.

### The Hypersthene-Andesites [23].

The oldest series of intrusives was erupted at a period contemporaneous with, or closely subsequent to, the time of the formation of the Lower Ashes and Agglomerates, and like them may be termed hypersthene-andesites. They are volcanic rather than hypabyssal, amygdular, and probably at one time were only cryptocrystalline and perhaps glassy. With the Lower Ashes and Agglomerates they have long been known under the name of 'Arenig Porphyry,' and are now being quarried at Arenig Railway-station as 'Arenig

Granite.' In composition they agree exactly with the Lower Ashes and Agglomerates, as also with many of the lavas and sills of the Stapely Volcanic Series of West Shropshire, but are more thoroughly silicified. In general, the intrusions take the form of rather thick sills, and occur above or below the Great Agglomerate. They are also frequent among the Platy Ashes above the latter, and, as shown in the map (Pl. XLI), extend downwards almost to the Llyfnant or *Extensus*-Flags, and upwards as far as the Daerfawr Shales.

In several places, as at Bryniau Poethion or about Llyn Crafanc, actual transgressions can be made out. The thickness of the sills varies enormously, but even the centre of the largest sill which is quarried at Clogwyn-y-Fran close by Arenig Railway-station, and is quite 200 feet thick, has spasmodic large vesicles; and smaller sills, which have lost the filling of their amygdulæ, frequently appear quite spongy. All the sills are more or less columnar in their jointing, the thicker almost as much so as the basalts of the Giants' Causeway. The best columns seem always to belong to the under, and not to the upper, surface of the sills.

The question of the intrusive or extrusive origin of the sills has been an open one ever since the time of Sir Andrew Ramsay, who was unable to make up his mind on the subject, and it is only after a good deal of work that I have been able to conclude that they are in the main intrusive. Even now, I picture some submarine volcanic cone sealed between successive eruptions by the chilling action of the sea, until eventually it became easier for the welling lava to spread itself among the accumulated rubbish than to burst asunder the cone and pour out over the surface. There is no corresponding set of intrusions among the ashes of the Upper Series, which have suffered far more contemporaneous decomposition than the members of the Lower. For this, and for other reasons, I am inclined to regard the Upper Series as, in part at least, a series of subaërial accumulation.

The total mass of the andesite-intrusions must be enormous, and is quite as great as the whole of the rest of the Lower Volcanic Series. Like the Great Agglomerate, the intrusive sills are always thicker and more abundant in the north-east than in the south-west of the district,

Under the microscope, it is seen that the rocks were formerly andesites, but that they have undergone a great deal of subsequent silification and other alteration. The sole really-fresh original minerals are the feldspars and the apatite. The former are beautifully preserved, and are mostly oligoclase or andesine, usually with narrow extinctions and showing Baveno or window-twinning, in addition to the ordinary albite-twinning. Sometimes the crystals are beautifully formed, while in others the growth has been checked at the skeleton or spongy stage. A certain amount of orthoclase is occasionally met with, but is not especially abundant. The apatite is extremely characteristic, and occurs in elongate hexagonal needles which are unusually large for so fine-grained a rock.

Ferromagnesian minerals are, so to say, rather at a discount, and are as a rule represented by ramifying veins and good pseudomorphs of spherulitic pale-green chlorite, which is probably delessite. Some of the pseudomorphs are exceedingly well formed, and, from their constant octagonal cross-section and elongate outline, are almost certainly after a rhombic pyroxene, which was probably hypersthene.

The groundmass of the rocks is always recrystallized and probably always silicified; when well preserved it shows a parallel or variolitic arrangement of rather stumpy microlites of plagioclase set in a coarsely micropoecilitic or granular mosaic of quartz or untwinned feldspar (4653-54 & 4657, 4659). Half-digested fragments of some ophitic andesine-bearing rock, quite like the later dolerites of the district, are frequently enclosed in this rock as in the corresponding Stapely rocks of Shropshire (4661). The infilling of the larger vesicles is usually calcite, that of the smaller ones is sometimes calcite, but more frequently quartz or spherulitic chalcedony. Some of the cavities have both quartz and calcite, together with a little chlorite; and, in these, it is worthy of note that the calcite is usually external to the other minerals (4655-56 & 4658, 4660).

#### The Andesitic Dolerites [24].

Just as the hypersthene-andesites tend to follow the horizon of the Great Agglomerate, the andesitic dolerites spread themselves abundantly about the horizon of the unconformity and the Basal Grit. Unlike the andesites, however, they range in a series of minor masses far down into the Cambrian, and in two localities extend upwards as far as the Great Agglomerate, in one place entering the Daerfawr Shales. Being of a rather basic character, they are usually much chloritized and very far from fresh, yet petrologically are quite interesting. They are always non-porphyritic, and generally to some extent ophitic. They contain from 53 to 56 per cent. of silica. Though occasionally slightly vesicular along their edges, they are distinctly hypabyssal in the mass of the rock, and range almost to gabbros in the centre of the larger laccolites. Vesicles, when present, are always filled with calcite (4664). Although I suspect, I have not been able to prove, chemical differentiation between the centres and edges of masses: such variations in silica-percentages as do occur seem irregular in their distribution.

Under the microscope, it is seen that the rocks belong to a rather acid type of dolerite, and that the ophitic structure is by no means constant in them.

The great bulk of the rock consists of a plagioclase-feldspar with an extinction-angle ranging on symmetrically-cut albite-twins up to 20°, but rarely higher. On powdering the rock, it was found that nearly all the feldspar floats off in a mercury-and-potassium iodide solution of specific gravity 2.68, sinking again when the specific gravity is reduced to 2.64. Cleavage-fragments so obtained showed extinction-angles never greater than 8°, and mostly gave only 1° or 2° upon the second cleavage. The feldspar is, therefore, almost

certainly andesine; and as the crystals are mostly elongate and have a parallel or roughly-variolitic arrangement, the rock may be termed an andesitic dolerite. The augite of the rock is in somewhat smaller proportion than the felspar: it is a pale yellowish or greenish variety, shows bright yellows between crossed-nicols, and has the usual extinction about  $34^{\circ}$ . It, too, is frequently quite idiomorphic, especially where fresh, but in other cases may enclose the andesine optically. In addition to this, there is also a small proportion of another, still more colourless, pyroxene, with higher refractive index, which gives greys between crossed-nicols and has almost straight extinction. This is probably a hypersthene with a wide angle between its optic axes, and is extremely like the hypersthene of the Tremadoc sills, as also that of the dolerites of the Shelve country. Ilmenite, in networks of skeletal bars, and apatite, in minute elongate needles, are also notable, as at Penmaenmawr. As alteration-products, chlorite of the form delessite, calcite, and chalcedonic quartz are only too abundant, and pale and dark epidotes occur (4665). The delessite is remarkable for the way in which it ramifies between and around the best idiomorphic felspar and augite-crystals, and during the weathering gives a sort of pseudo-ophitic aspect to rock which was even once panidiomorphic. Frequently it also forms good well-shaped pseudomorphs after the elongate octagonal crystals of hypersthene. The quartz present is nearly all chalcedonic; and although I have sought for, I have not been able to find, any micropoecilitic or eutectic intergrowths between it and the felspar (4662-63).

From the fact that the andesitic dolerites enclose pieces of *Shumardia*-Shale with undistorted fossils, and that the slightly-hardened shales of that series which adjoin them are entirely uncleaved, one must conclude that the date of intrusion was prior to the cleavage of the country. From the way in which the intrusive sills seem to spread themselves in the neighbourhood of certain faults, one might think that their intrusion was connected with the formation of some of these. As will be seen from the foregoing descriptions, the andesites and the andesitic dolerites appear to be closely related; and as the former, which are also the older, contain half-digested fragments of the latter which are newer, both would seem to have come from the same subterranean magma-basin. In this, as in all other particulars, the andesitic dolerites closely resemble the Shropshire dolerites which, as shown by Prof. Watts,<sup>1</sup> occasionally cut strata of Llandovery or even Wenlock age, and I have every reason to think that all are of the same general age.

### Other Intrusions [25].

Of other intrusions I need only mention the curious granular andesites, which are so common at the horizon of the *Niobe*-Beds, and the hornblende-porphyrates, which are seen intrusive among the Middle *Lingula*-Flags (Ffestiniog Beds) to the west of Blaen-lliw.

<sup>1</sup> Proc. Geol. Assoc. vol. xiii (1894) pp. 339 *et seqq.*

The granular andesites occur in a series of rather small sills, which seem to be arranged en échelon along the bedding-planes among the *Niobe*-Beds. They contain just a few rounded phenocrysts of oligoclase or orthoclase, but are, on the whole, non-porphyrific. They closely resemble the groundmass of andesites of the main series, but are even more thoroughly recrystallized, and show quite a coarse-grained mosaic of micropoecilitic feldspar. The original microlites are short and rather stumpy, and appear to show good flow-structure. The microlites are arranged without any reference to the micropoecilitic patches, and frequently lie across the boundary between two of them (4666-68). On weathering, a great deal of calcite is formed between the micropoecilitic patches, and this, dissolving away upon the surface, gives the rock a very characteristic sugary appearance in the field.

The hornblende-porphyrites are only represented in this district by a single sill, but as this is exposed upon its dip-slope, it occupies a very considerable tract of ground, which unfortunately, however, is mostly covered with Drift. Where seen, the rock seems very like the more basic porphyrites of Rhobell Fawr,<sup>1</sup> and contains delightful porphyritic crystals of green hornblende and well-formed Carlsbad twins of a plagioclase-feldspar (4669-71). Unfortunately, no specimens fresh enough to slice are as yet to hand, and a further consideration of this rock must therefore be postponed.

### The Cleavage.

Considering its geological position in the midst of the greatest slate-producing region of the world, the district of Arenig Fawr and Moel Llyfnant is remarkably free from cleavage. When one follows the outcrop of the various series to the south or to the north-west for even only a few miles, one is struck by the notable increase in the intensity of the cleavage; and hence, though not able to bring forward much evidence, I am inclined to think that the absence of cleavage here is due to the accident of the district being, as it were, the keystone of the great Harlech dome.

Further, I find that the cleavage of North Wales, as a whole, has a Caledonian or north-easterly to south-westerly trend, and that the average strike of the rocks of the Arenig area is transverse to this. I should therefore suppose that the great masses of unyielding and uncleaved igneous rocks of the district may have transmitted earth-pressures along their length without suffering much deformation, and so may, for a time at least, have held off the stresses from the adjoining softer rocks. I notice also that there occur in the area no rocks the trend of which is now exactly north-west to south-east, but that all strikes change abruptly at a series of faults from north-and-south almost to east-and-west. Such faults I regard as marking the stage when the rigid igneous rocks could no longer stand the strain, and so gave way, as it were, with a rush; and I should like

<sup>1</sup> G. A. J. Cole & T. H. Holland, *Geol. Mag.* 1890, p. 452.

to explain the rucking-up, local thickening, and pinching-out of such soft beds as the Daerfawr and *Bifidus*-Shales as due to the adjustments between the rigid masses consequent on local pressure-reliefs produced during the process.

As to the age of the cleavage, we have already seen that it is later than the intrusion of the andesitic dolerites. It is, therefore, probably post-Silurian; and as, from the relations of the Carboniferous, it must date from long before the Carboniferous Limestone, we may tentatively refer it to the age of the Old Red Sandstone or Devonian.

### The Structure.

The general structure of the district is that of a terraced escarpment, broken both transversely and longitudinally by faults. The scarp as a whole is determined by the Volcanic Series described, and extends more or less continuously right round the Harlech dome, from Tremadoc by the Moelwyns, Manod Mignant, the Arenigs, the Arans, and Cader Idris, to the sea again near Towyn, the Arenigs being the easternmost outpost of the ring.

As has been indicated, the Massive Ash of the Upper Series forms the culminating ridges of both Arenig Fawr and Moel Llyfnant, which have also their eastern slopes largely determined by its dip. A prominent terrace or secondary scarp is determined by the Andesites and Agglomerates of the Lower Volcanic Series, and runs round high up on the western flanks of both mountains. About Craig-y-Bychan, Maen Grugog, and Craig Henllan this feature so spreads out as almost to determine separate mountains. The Llyfnant Flags, and with them the andesitic dolerites, give rise to broken ground at lower levels, but do not stand out sufficiently to determine striking structural features.

Of faults, two series are of great importance. The older of these has a general transverse Caledonian, north-westerly to south-easterly direction, and would seem to belong to the series of earth-movements which produced the cleavage of the district. Two of its members, one to the north and the other to the south of the summit of Moel Llyfnant, have produced notable displacements of the resistant rocks of the Volcanic Series, but appear to die out downwards in the soft shaly rocks of the Tremadoc and Dolgelly groups. That which determines the fine crags of Y Castell, south of Llyn Arenig Fawr, appears actually to die out in the Daerfawr Shale, and cannot be proved to cut the Lower Volcanic Series at all. These faults I regard as tear-faults; they are very like the faults described by Dr. Marr among the Coniston Grits and older rocks of the Lake District. The rocks in their immediate neighbourhood are always much shattered; and it is interesting to note that the pieces of fault-rock are mostly slickensided in a direction which makes only a small angle with the bedding of the adjoining country rock.

Parallel to these tear-faults are several fine examples of normal faults. The most important of these is the clean-cut fault which

passes close by Amnodd-wen, and gives the summit of Arenig its characteristic double peak. It has a throw of about 300 feet, and appears on the surface in turn as a gully and with fault-cliffs on either side successively. It seems to run right across the district, and is recognizable on both sides of the much later north-and-south fault; it has a notable hade to the north-east. Another important fault belonging to the same series is that which forms the waterfall at Pont Aberderfel. It passes close behind the Rhydy-fen Hotel, through Bwlch Llestri and on to Nant-yr-Achab. It is worthy of notice, because near Tai Herion it brings *Asaphellus*-Flags against *Extensus*-Flags and *Calymene*-Ashes, and, making there no feature, led the older geologists to record Arenig and Tremadoc fossils from the same locality.

The second great series of faults is represented only by one great example, which traverses the entire district, and cuts the country and all its structures completely in two. It was traced by Sir Andrew Ramsay in a direction a little west of north and east of south, for more than a dozen miles. It has a downthrow to the west, and at one place brings the Ashes of the Upper Series against the Lower Dolgelly, or even the Ffestiniog Beds of the *Lingula*-Flag series. It is much later than all other structures in the district, and from the frequent stories of earth-rumblings which one hears at the farms along its course, one must conclude that it is probably still in a condition of instability.

In addition to these faults, there are also a couple of rather gentle anticlinal folds which affect outcrops in the Tryweryn Valley, and again in the neighbourhood of Llechwedd Erwent. These would seem to be somewhat earlier than even the oldest faulting, and probably belong to the time of the intrusion of the andesitic dolerites. They have a Caledonian trend, and have taken a pitch corresponding to the general dip of the beds of the whole country. The more southerly example is cut off along its north-western flank by a fault.

### III. CONCLUSIONS.

This brings us to an end of our consideration of the solid geology of Arenig Fawr and Moel Llyfnant, and I may now briefly summarize the results which have been attained.

The rocks are divisible into an Upper and a Lower Series, which are separated by an unconformity. The Lower Series belongs to the accepted Upper Cambrian rocks of North Wales, and includes representatives of the Ffestiniog, Dolgelly, and Tremadoc groups, the last of these being incomplete upwards. The Ffestiniog and Dolgelly Beds are quite like the corresponding beds of both the Tremadoc and the Dolgelly districts, while the character of the Tremadoc is intermediate between that of the beds of Penmorfa and those of Sheinton, and is quite unlike that of the ashy beds described as Tremadoc at Dolgelly.



The Upper Series belongs to the Ordovician (Lower Silurian of some authors), and may be correlated division by division with the series described by Prof. Lapworth and Prof. Watts in the Shelve country. This series conveniently divides into a lower member of calcareous, gritty, or graptolite-bearing sediments, a middle member chiefly of direct volcanic origin, and an upper shaly member which is not described. The lower member is the equivalent of the Upper Skiddaw Slates of the Lake District, and is the Arenig of most British authors; whereas it was to the Middle Series that the name of Arenig was first applied by Sedgwick. The Volcanic Series is immediately overlain by beds belonging to the Caradoc or Bala Series, which are essentially Upper Ordovician in their fauna.

Having thus stated the facts, I leave it to others to suggest a way out of the tangle in which our nomenclature has become involved, and shall hope to hear the matter fully thrashed out anon.

#### IV. GLACIATION.

Forming, as the Arenig Mountains do, the highest ground in the neighbourhood of the main watershed of Wales, their glacial geology is perhaps worthy of passing notice. Of the period of maximum glaciation there is little record, and it is uncertain whether or not the mountains were ever entirely overridden by ice. Certain it is, however, that the highest summits are so much frost-split, that they would not be likely to retain such striæ as they might receive. No Drift has been found at higher levels than 2000 feet.

The stage when the ice stood at about 2000 feet is more interesting. Then and onwards, until it had retreated to about 1800 feet, all the important hilltops protruded as nunatakk, and withstanding the powerful ice-stream which came along from Snowdonia and other districts to the west, retained numerous big boulders of a black-looking felspathic agglomerate like the Glan-y-pwll trap-rocks of Blaenau Ffestiniog or Manod. Perched blocks of this rock frequently occur quite high up on Moel Llyfnant, and are particularly abundant on the Lower Agglomerate slopes below Craig-yr-Hyddod. They are quite distinct from any rock in the district. At this stage, the ice was able to supplement the local glaciation of the Blaen-Lliw Valley, and to send a weak lobe bearing a few Snowdonian boulders into the Erwent Valley. At this stage, too, the ice dragging round the Daerfawr-Shale ground under Daerfawr, towards the open low ground of Nant Hir east of Arenig Fawr, began the formation of the lateral moraine, which ultimately formed the barrier that holds up Llyn Arenig Fawr, and similarly passing round Arenig Fach to the Gelyn Valley also formed the barrier for Llyn Arenig Fach.

At a later stage, the ice-lobe crossing the col between Moel Llyfnant and Arenig Fawr became broken, and the part in the hollow to the north was left stagnant. In melting, this gave rise to a fine series of parallel ridges of morainic material, which, running

roughly parallel to the sides of the cwm, enclose the morass between Ceunant-y-gareg-ddu and Amnod-d-bwll.

The retreat of the ice from the 1800- to the 1500-foot level must have been comparatively rapid, and but little moraine can now be found between those limits. Below 1500 feet, however, moraines become abundant, and some of their terraces are exceedingly-well marked. One along the north side of the higher Tryweryn Valley is almost like a railway-embankment, and the same might also be said for that on the south-western flank of the Afon Tai-Herion Valley. Where these two meet, they have so overshot the outstanding crag of Craig Henllan that they enclose a triangular hollow, which (formerly a lake or tarn) is being rapidly drained by a small outflow-stream, and is now only an impassable bog.

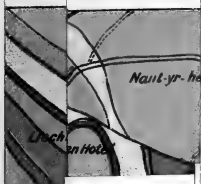
The moraine which holds up Llyn Arenig Fawr is also mainly at this level. Unlike the moraines at 1800 or 2000 feet, those at 1400 to 1500 feet are almost wholly local in their origin; and I am inclined to think that, at the time of their formation, the ice-shed lay much nearer the present watershed than at the earlier stage. The later glaciation, however, was no small phenomenon, for the Drift includes boulders of enormous dimensions; and though only the andesitic dolerites and intrusive andesites retain their scratches, all rocks within its boundaries are exceedingly-well moutonnés.

A still later stage in the glaciation is marked by the accumulation of various tumps and roughly-crescentic mounds of Boulder-Clay and ill-sorted gravel in the valley-bottoms. One of these, occupying the upper end of the old valley-channel south of Foel Bodrenig, through which the railway now runs, was probably responsible for the diversion of the Afon Tryweryn over the beautiful falls of Boch-y-rhaidr, and the consequent formation of the great peaty flat above the falls. The origin of the lake of Tryweryn is not at all clear; but as it lies almost upon the watershed, is shallow, and has its exit over obvious Drift, we may reasonably conclude that it too is due to similar causes.

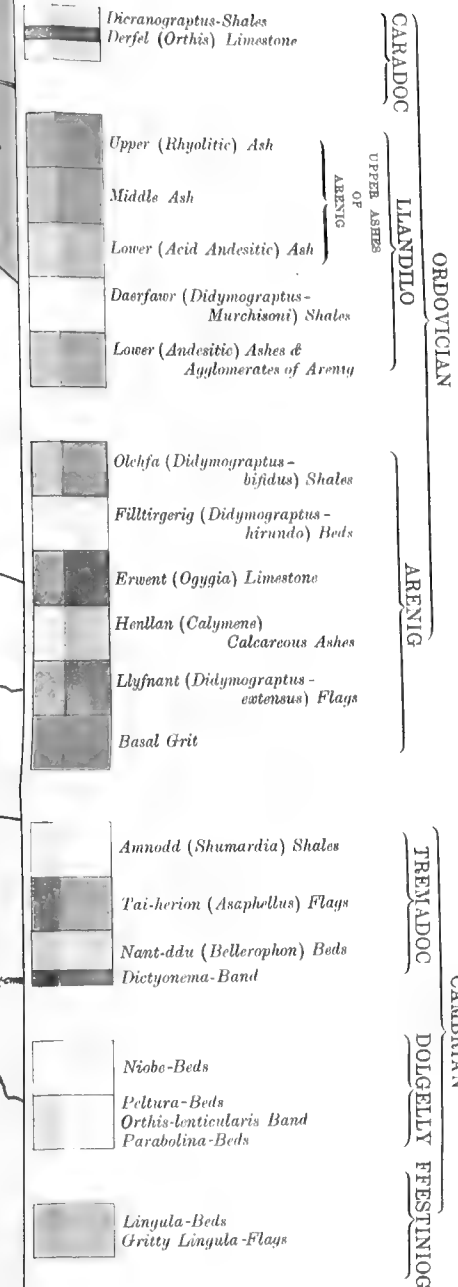
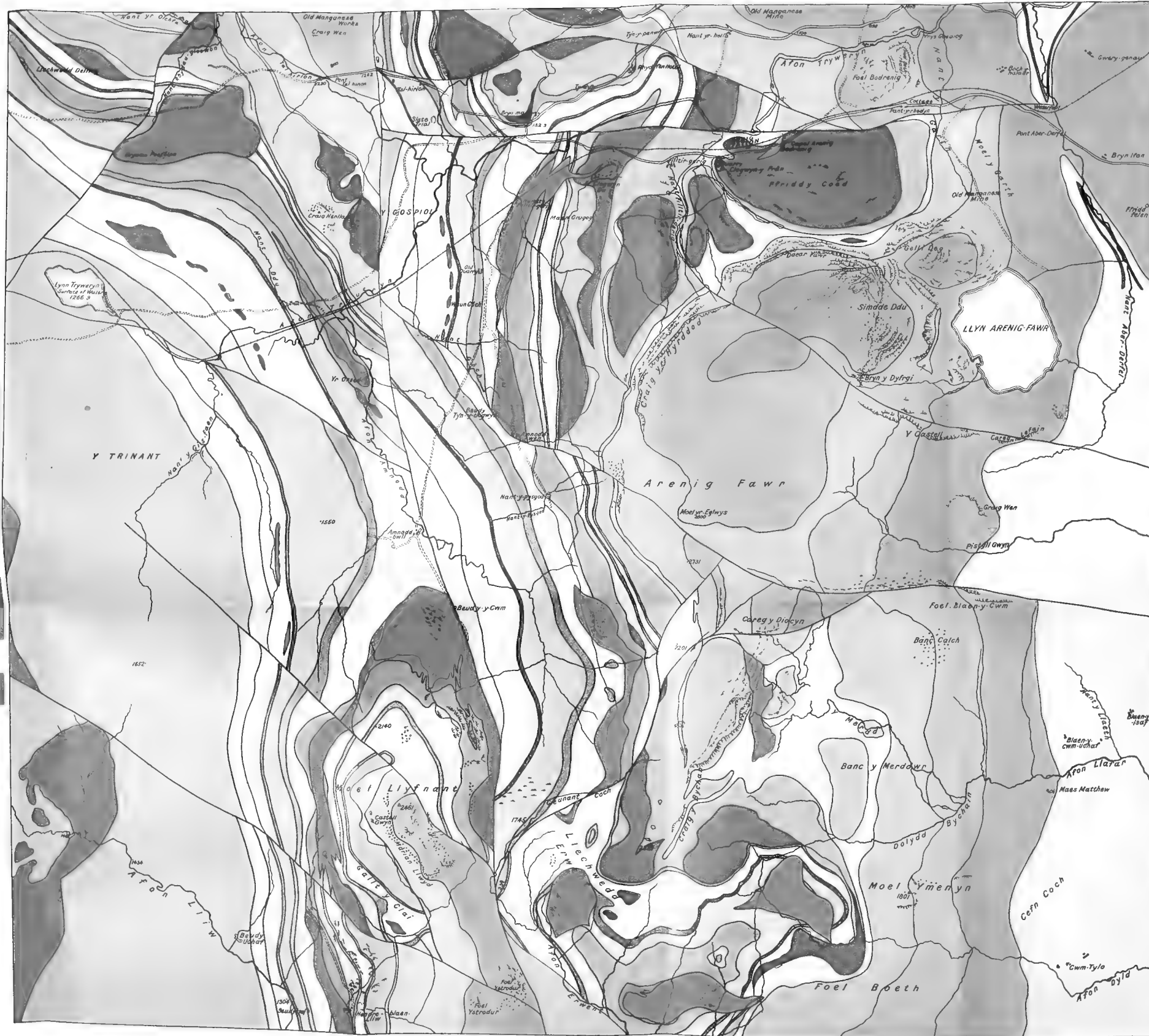
No evidence of any glacial overthrow-valleys has been detected, but as the ice never advanced into any important valleys, this is hardly to be wondered at. The dip-slope valleys on the east of Arenig do not seem to have ever been seriously glaciated, and are much choked with frost-talus.

In conclusion, I desire to express my best thanks to Dr. J. E. Marr, F.R.S., P.G.S., for his constant good advice and encouragement in the working-out of the succession; to Miss Gertrude L. Elles for her aid in identifying my graptolites; to Mr. R. H. Rastall, F.G.S., and all the various junior members of the Cambridge Geological School, who have shared and helped me to enjoy the glorious solitudes of Merionethshire; and to all the various land-owners, tenants, and hospitable farmers, who have allowed me to wander free over the country and find out whatever new information is contained in this paper.

My thanks are also due to the Director-General, and especially







IGNEOUS ROCKS

CONTEMPORANEOUS

Upper Rhyolitic Ash  
Middle Ash  
Lower (Acid Andesitic) Ash

Lower (Acid Andesitic) Ashes & Agglomerates of Arenig

INTRUSIVE

Hypersthene-Andesite  
Andesitic Dolerites

Hornblende-Porphyrates

GEOLOGICAL MAP OF ARENIG FAWR AND MOEL LLYFNANT. SCALE: 3 INCHES = 1 MILE.

BENROSE, DERBY



to Mr. H. H. Thomas, M.A., F.G.S., and other officers of the Geological Survey, at Jermyn Street, by whom the colour-model of the map was prepared.

#### EXPLANATION OF PLATE XLI.

Geological map of Arenig Fawr and Moel Llyfnant, on the scale of 3 inches to the mile. The topography is based on the Ordnance-Survey map, and consequently the mutation in the spelling of certain place-names, etc. differs occasionally from that adopted in the text of this paper.

#### DISCUSSION.

The PRESIDENT said he was glad that the Author had turned his attention to Sedgwick's area of typical Arenig rocks. The founders of our systems had been obliged to draw the lines between different series of those systems somewhat vaguely, and it was desirable, in the light of our increased knowledge of fossil-horizons, to ascertain what fossil-horizons were represented in these typical districts. The Author had availed himself of the information which Prof. Hughes and Mr. G. J. Williams had generously placed at his disposal, and was able, as the result of this and of his own work, to give us important information concerning the *Lingula*-Flags and Tremadoc Slates, as well as the Arenig rocks.

With regard to the line between the *Lingula*-Flags and the Tremadoc Slates, if the *Dictyonema*-Bed were taken as the horizon of separation, the *Psilocephalus*-Beds of Tremadoc, once placed in the Tremadoc-Slate Series, must be assigned to the *Lingula*-Flags. It seemed desirable that this should be done.

The occurrence of the Shineton fauna in Wales, originally proved by Williams in the Arenig district, had also been detected by the Author in that of Tremadoc, and he had largely added to our knowledge of those beds, which occurred below the well-known *Angelina*-Beds. The term '*Shumardia*-Beds' used by the Author seemed appropriate.

Passing to the Arenig rocks of Arenig, the Author mentioned the occurrence of *Loganograptus* in his *Extensus*-Beds. It would be interesting to know whether the rich assemblage of *Loganograpti* and *Dichograpti* found in Lakeland, Scandinavia, Canada, and Australia would be eventually discovered in these beds, in order to ascertain the nature of the earliest fauna of these Arenig rocks.

The poverty of the fauna of the Daerfawr Shales was a matter for regret. If these shales were referable to the *Murchisoni*-horizon, the shales and the great mass of Upper Ashes were not of Arenig, but of Llandeilo age. But there was still a difficulty. Where were the Upper Llandeilo Beds? He (the speaker) had a dim recollection of having seen a specimen of *Ogygia dilatata* collected by Williams from shales above the ashes, but would not speak with certainty. But, so far as the tract described in the paper was concerned, the Author gave reasons for supposing a

passage between the Daerfawr Shales and the Upper Ashes, and between the latter and the *Orthis*-Limestone. This limestone the Author referred to the Caradoc Series, and the fossils seemed to bear out his view; but it was distinctly a surprise to find Caradoc rocks in that locality.

Mr. A. P. YOUNG remarked on the unsettled use of the term laccolite, and wished to ask how far the structures studied by the Author resembled those intrusive masses to which the name in question was first applied. The floor of country-rock, the vaulted roof, and the absence of any channel of communication with the surface, seem to be essential characters of a laccolite, as originally described.

Prof. HULL expressed his high appreciation of the geological mapping of the Author in the Arenig Mountains; and emphasized the great advantage in the present day of having maps on the 6-inch scale, compared with those on the 1-inch scale (which were the only maps available in the old days of the Geological Survey, when the district was being mapped by his deceased colleagues, Ramsay, Selwyn, Jukes, and Aveline). It was under these able men that he (the speaker) had his first lessons in field-geology among these mountains, when he assisted in levelling the horizontal sections over Aran, Cader Idris, and Snowdon. He believed that he was correct in saying that the view of the Government surveyors, as regarded the Arenig range, was that the great sheets of felspathic trap described by the Author were in a certain sense 'contemporaneous,' and not 'intrusive,' except that they had been extruded from time to time over the floor of the sea; a view which the occurrence of great beds of volcanic ash with marine fossils tended to confirm. On the other hand, the dykes of diorite and dolerite, and other basic rocks which traversed the Arenig Beds, were undoubtedly intrusive (in the ordinary sense) and of later age.

Prof. WATTS compared the succession at Arenig with that worked out by Prof. Lapworth in Shropshire. The main volcanic series was above the zone of *Didymograptus Murchisoni* in the former district, and below it in the latter. But the chief members of the Arenig succession could be compared fairly closely. A strong resemblance also existed between the petrological characters of the andesites and the intrusive dolerites in the two areas, and there were similar difficulties as to the conditions of the outpouring or intrusion of the andesites. It was somewhat difficult to compare the Tremadoc rocks in the two localities.

Prof. T. McK. HUGHES thought that the Society would allow that circumstances had laid the task of bringing before the Society the results of researches on the Arenig and associated rocks of the Arenig Mountain upon one well qualified by his stratigraphical, palæontological, and petrological skill to deal with it. He would only add a few remarks, on some of those points as to which there was less agreement. The Arenig of Sedgwick was defined to be the shales tangled among the volcanic rocks of the western front of



the mountain. He had visited the district with Ramsay and Aveline when the difficulty of fixing a base first became acute, and as the grit so well seen between Portmadoc and Garthbarn seemed always to occur where the palæontological change from Tremadoc to Arenig set in, it was taken as the base. This was founded chiefly upon J. W. Salter's palæontological work, for in those days they had no detailed succession based upon the graptolites, such as Miss Elles had now established. The chief difficulty about this base was, that although at Portmadoc the grit rested upon shales which contained *Angelina* within an inch of its base, at Garthbarn the grit was divided by a fossiliferous shale, and farther on towards Tan-y-bwlch it was represented by several lenticular beds of grit, so that some grits were well up in the Arenig, while the overlapping beds of the Arenig crept one over the other on to various parts of the unconformably-underlying Tremadoc. At the top of the Arenig also there was a difficulty as to the best place to draw the upper boundary, because the beds which cropped out farther west towards Bala (and had always been taken as Bala) reappeared on the top of Arenig Mountain. As, however, the Arenig passed up into the overlying Bala, this was only a small matter of convenience of correlation. The question was asked, where then was the Llandeilo? He pointed out that across the middle of the island there was evidence of an east-and-west movement, which had not had much effect on the beds up to the top of the Tremadoc, but had resulted in a different stratigraphical and palæontological facies in the Arenig, Bala, and Silurian. In the south, a number of limestones occurred in the Silurian, without which the divisions would never have been drawn where they were; while the muddy and sandy sediment of the northern area differed much from that of the south. So in the Arenig and Bala Series a number of volcanic rocks occurred in the northern area, showing that the conditions were different there from those which prevailed in the south. The Llandeilo group was not absent owing to any unconformity or contemporary erosion, but simply because the conditions affecting sedimentation and life were different, and sufficient data were not yet available to determine which deposits were being laid down in the Arenig area when the Llandeilo Flags of Caermarthenshire were being formed.

Mr. P. LAKE drew attention to the similarity of the lower part of the Author's sequence and that of the Dolgelly district, described by Prof. Reynolds and himself. Up to the *Dictyonema*-Beds the correspondence was precise, excepting for the fact that the *Niobe*-Beds had not yet been recognized at Dolgelly, probably on account of the poorness of the exposures. But the *Bellerophon*- and higher beds were apparently absent at Dolgelly, or were perhaps represented in part by the volcanic beds which appear a short distance above the *Dictyonema*-Band. The most remarkable feature, however, was that at Dolgelly, as in the Arenig district, the Tremadoc Beds were covered unconformably by laccolitic masses or sheets of doleritic rock. Prof. Reynolds and the speaker had inferred that these had been intruded along an unconformity; but, as the overlying

beds had been entirely removed by denudation in the area mapped, they were unable to determine the age of the unconformity. The Author's observations rendered it highly probable that it was the same unconformity as that which he had described at the base of the Arenig Series. In conclusion, the speaker desired to add his thanks to those of the previous speakers, for the very careful and valuable piece of work which the Author had brought before the Society.

Mr. H. H. THOMAS congratulated the Author, on behalf of his colleague, Mr. T. C. Cantrill, and himself, on the excellence and general utility of his work; for it was always desirable to have a classical area competently revised, with the help of modern methods of research. He remarked on the striking similarity, both lithological and faunal, between most of the members of the Arenig and Llandeilo rocks of the Arenig district and similar horizons in South Wales, over that part remapped by the Geological Survey in the past three years (Llandeilo to Whitland). He considered that in the two areas it would be quite possible to correlate the Arenig and Llandeilo rocks, bed for bed. In South Wales there was no unconformity at the base of the Arenig Series.

The PRESIDENT said that there appeared to be differences of opinion on some points among previous speakers, as to matters of detail, but all were agreed as to the value of the paper. He was glad to add his testimony on this, to that of the other Fellows who had taken part in the discussion.

The AUTHOR thanked the President and Fellows for their kind reception of his paper. In reply to the President, he suggested that the *Extensus*-Flags included a representative of the highest part of the 'Many-branching graptolite'-fauna of the Lakes and elsewhere. With the President and Prof. Watts, he too was not satisfied as to the entire absence of the Upper Llandeilo Beds, but had hunted for them in vain all over the district discussed. He remarked that Upper Llandeilo Shales were exceedingly well developed in the district west of Tremadoc and all along the north-western margin of Snowdonia, but even there were locally quite pinched out. He hoped to clear up the matter by future work in the intervening districts. In reply to Mr. Young, he said that he had used the word laccolite to describe rather large cake-like masses of intrusive igneous rock, the general extent of which coincided with the bedding-planes of the neighbouring sediments, and the thickness of which was considerable (about  $\frac{1}{20}$ ) compared with their linear extent. He particularly thanked Prof. Watts and Messrs. Lake and Thomas for their useful and valuable hints as to the correlation of the beds of the Arenig district with those of other areas.

30. NOTES on the GEOLOGICAL ASPECT of some of the NORTH-EASTERN TERRITORIES of the CONGO FREE STATE. By GASTON FÉLIX JOSEPH PREUMONT (*communicated by J. A. HOWE, B.Sc., F.G.S.*); with PETROLOGICAL NOTES by JOHN ALLEN HOWE, B.Sc., F.G.S. (Read April 19th, 1905.)

[PLATES XLII-XLIV.]

I. INTRODUCTION.

IN 1902 I had the honour of being commissioned by the Government of the Congo Free State, as mining-engineer and geologist, to accompany an exploratory mission sent to their north-eastern territories, and I had the opportunity of taking a few notes on the geological aspect of that part of Africa, which is as yet little known to the geologist.

It has occurred to me that the observations recorded during nearly two years spent in that region, although no doubt very incomplete, might possibly be found of some interest.

The Government of the Congo Free State have given me in Africa in a very generous way, through all their officials, every assistance to carry out the investigation of that large tract of country: and I beg to be allowed here to mention my debt of gratitude towards them, as also to thank the Secretary-General of the Interior, Commandant Liebrecht, for the kind permission which he has granted me to bring these notes before this Society.

I am also greatly indebted to Mr. J. Allen Howe, who has kindly undertaken the petrological description of the rocks, for his valuable assistance and advice.

The Uelle district and the Lado Enclave are the north-easternmost provinces of the Congo Free State. They cover an area at least six times as large as Belgium, and the Uelle district alone extends over 72,000 square miles. On the map it presents the shape of a long and broad belt of country nearly parallel to the Equator, stretching approximately from lat.  $2^{\circ} 30'$  to  $5^{\circ}$  north, and from long.  $23^{\circ} 30'$  to  $32^{\circ}$  east of Greenwich. Eastward it reaches as far as the Nile, and adjoins there the Uganda Protectorate. Northward it is bounded by the Egyptian province of Bahr-el-Ghazal, and farther west is divided from the French Congo by the River Mbomu, which by joining the Uelle River forms the Ubangi. On the south-west and south it is contiguous to other provinces of the Free State. The south-eastern extremity of the country so described reaches to Lake Albert.

From Boma, the capital of the State, on the Lower Congo, access is gained to the Uelle district by the usual route to the interior, namely, from Boma to Matadi by steamboat on the Lower Congo;

from Matadi, a line of railway, 260 miles long, crosses the mountainous belt of the Sierra de Cristal, and reaches the Upper Congo, which becomes once more navigable at Stanley Pool. From there large steamers ply regularly on the river, and cover in about 18 days the distance between Léopoldville and Bumba. Thence two or three days more enable the traveller to reach Ibembo, port of entry of the Uelle, situated on the River Itembiri, a direct tributary of the Congo.

The means of communication in the Uelle district are somewhat more primitive, and consist generally, either in using native canoes for travelling over the rivers (frequently full of rapids), or else in tramping overland along the native paths. Roads for wheeled traffic do not yet exist, although the Government is now laying some out.

As in most parts of Africa, the work of exploring and of collecting observations in the Uelle is rendered somewhat tedious, if not actually difficult, by the nature of the country and its local conditions. In the Equatorial Forest one feels almost as if buried underground; the field of observation is reduced to the narrow strip of the native footpath, and one goes often a day's march before meeting with any rocks *in situ*. In the vast plains of the north the same difficulties are found again, caused here by long grass, through which it is often necessary to cut a road. Only for three months in the year, after the grass has been burnt, can this obstacle be considered as slight.

The climate, though far from being as bad as it is represented, is nevertheless not one which conduces to the exertion of a maximum of energy in the field.

### Itinerary.

I will now try to give a brief idea of the ground covered in our itinerary.

The object of the first part of our journey was to reach Ndoruma, the northernmost station of the State in the Uelle district. Proceeding by the River Itembiri, from Ibembo, to Buta, we crossed here, overland towards the north, and reached the Uelle at Bima. From Bima we then followed the River Uelle quite closely, and for the most part, by land-route, up to Niangara. Thence we proceeded across country in a northerly direction to Ndoruma. From this locality, which was for some time our base, we had the opportunity of seeing the country directly north of it, and of inspecting also the district east of it, as far as the hills of Mount Bundukwa.

The second portion of the journey comprised a visit to the country situated between Dungu and the neighbourhood of Mount Gaima; thence towards Farach and the Lado Enclave, through the central part of the Nile Territory, as far as the Nile itself. Finally, returning from the Nile Territory, we traversed the mountainous portion of the Uelle district, situated near Arebi, and later took a route more to the south, in order to visit Mount Tena. We returned to Buta by Poko, Zobia, and the Lipodongu Falls on the Rubi.

## II. PHYSICAL FEATURES.

A large extent of the Uelle district is very densely wooded, being part of the great Equatorial Forest, which stretches as far as the Bomokandi and Uelle rivers. North of these, the country consists generally of vast plains covered with grass and scrub, intervening between broad valleys, into which the forest sends out prolongations from its main area: the forest-growth naturally following the water-courses. The country reaches its greatest elevation towards the east, at the Nile-Congo watershed, where it attains an elevation of 3300 feet, and, in places, as much as 4000 feet; on the south-east, a wide area is hilly and even mountainous. In the north-eastern part, close to the Bahr-el-Ghazal, appears a group of hills of some importance, with Mount Bundukwa, Mount Yambili, and several smaller elevations.

Westward, the country becomes gradually lower and forms a series of broad undulations which produce hardly any visible effect on the contour. Through this monotonous country pierce, in places, groups of isolated hills, such as Mount Angba, on the Uelle, near Amadi; Mount Madjema, near Poko; Mount Tena, on the Bomokandi; and others of minor importance.

Close to Libokwa, a ridge of granite running north-west and south-east stretches quite close to the southern bank of the Uelle, and extends towards the Falls of Lipodongu on the Rubi.

The Uelle district is extremely-well watered. The Uelle River arises from the mountains situated near Lake Albert, and traverses the district from east to west, throwing its network of tributaries northward and southward, over a wide area representing more than 60,000 square miles. The southern tributaries are the most important; a fact easily accounted for, since the southern zone is more densely wooded, and has a rainfall heavier than that prevalent in the northern zone.

A rough parallelism is noticeable in the disposition of the principal affluents of the Uelle: north of the river the tributaries all run nearly north-east and south-west, while those on the south side trend more west-north-westward and east-south-eastward.

Owing to the small fall of the rivers and streams the country, in the rainy seasons, becomes extremely swampy: small rivers, of no importance at other times, often expanding over enormous flood-grounds. This is especially noticeable in the northern zone, where the country is more level and the ground more argillaceous. The Uelle, in common with most of its tributaries, generally winds its way through high banks of clayey alluvium, and runs through a broad basin, much too shallow to be termed a 'valley.' The course of the stream is interrupted by numerous rapids, which divide it into reaches of quieter water, easily navigable for native canoes. In flood-times the Uelle rises from 12 to 15 feet, and its volume of water is increased at least fivefold.

That the pitch of the river is not great is instanced between Suronga and Niangara, the difference of level being 42·6 feet for a distance of a little over 62 miles, with only two insignificant rapids.

## III. GEOLOGY.

## Ibembo—Buta. Lipodongu. Itembiri—Rubi Basin.

On leaving Ibembo, to proceed up the Itembiri River, towards Buta, the first rocks encountered are at the rapid of Gô, where the river changes its name into Rubi.

The Buta Shales.—Beyond the junction of the Likati River with the Rubi, appears a formation of laminated shales horizontally stratified, and cropping out on the river-banks. They are in appearance quite unmetamorphosed, and in places seem to pass into sandstone. They continue to be seen along the banks of the Rubi, right up to Buta.

Close to Buta, and apparently intercalated in the Buta Shales, is a small outcrop of oolitic limestone in irregular masses, many cubic yards in size, which are buried in a light-coloured clay-soil, forming here the southern bank of the Rubi. The forest, hereabouts very dense, prevents one from making a detailed investigation, and no information could be gathered as to the relative position of this outcrop with regard to the neighbouring shales. It looks like a local occurrence of no great extent. All along the Rubi River the Buta Shales are most regular in appearance, and quite horizontal in position. They do not seem to extend to any considerable distance northward or eastward, as, in following up the course of the River Rubi (a road which we travelled on the return-journey) they are only traced for about 20 miles farther east, a little before reaching the Falls of Lipodongu on the Rubi, where granite appears.

Northward we followed the Buta Shales up to the Bali River, about 12 miles north, where we noticed an outcrop of soft grey sandstone, apparently running north-westward and south-eastward.

Granite.—Between the Bali and Libokwa, and about 30 miles north of Buta, a well-defined massive ridge of granite appears, running in a north-westerly and south-easterly direction; and the intervening country is made up of alluvium and clay in the depressions, while upon the slight eminences a limonitic puddingstone is often met with. From Libokwa to Bima on the Uelle, the same granite and ferruginous rocks are also abundant.

The altitude of the Rubi basin at Buta is about 1600 feet above sea-level, and that of the Uelle at Bima is about 2000 feet. Since the distance between the two places does not exceed 55 miles in a bee-line, the ascent is remarkable, and makes the basin of the Uelle much higher than that of the Rubi. The separation of the two basins is well-defined by this ridge of granite running westward close to the Uelle. South-eastward this granite-ridge appears to extend in the direction of the Lipodongu Falls on the Rubi.

In entering the Uelle Basin, therefore, the main fact to be noticed is its granitic substratum.

## Djabbir—Likati.

From Bima to Djabbir the Uelle takes a more north-westerly direction, and its course is interrupted by an immense number of rapids. We had no opportunity of visiting that part, but from the information gathered it would seem that granite is the prevalent rock.

A remarkable feature of that stretch of country is the peculiar direction, as well as the proximity of the course of the Likati River in its upper part, to that of the Uelle itself, there being an interval of not more than 15 miles between the two rivers.

Commandant Roget is said to have found a stanniferous diabase on the banks of the Uelle and in the neighbourhood of Djabbir. We have been unable to verify this, and in the portion visited by us we never saw any stanniferous rocks.

## Bima—Bomokandi. Poko—Zobia.

The distance between Bima and Bomokandi is given as 81 miles (*teste* Lemaire) by the waterway, the difference of level between the two places being about 82 feet.

As we travelled this route by canoes at the highest flood-time, little information could be gathered, except to show that the country was entirely granitic in its nature. At the numerous and strong rapids encountered, blocks and masses of granite were much in evidence, and near Bomokandi we noticed that the granite formed a ridge running north-west and south-east.

On the road followed overland from Poko to Zobia, and thence to the Rubi on our return-journey, we obtained a new traverse of the same country, but farther south. Here again granite was the prevalent rock, being principally found in the depressions and beds of streams, and mostly in isolated blocks buried in clay. In places, the lower portions of the grey argillaceous deposit, as the underlying granite was approached, became more and more like kaolin, and we observed that it was often used as whitewash for houses.

Above the kaolinized surface-deposit, which we take to represent the decomposed granitic substratum, we noticed a formation overlying it and distinct from it, which appears to be widely distributed throughout the Uelle district: a limonitic puddingstone, to which I shall refer again (p. 649).

From Bomokandi to Amadi the distance overland is about 55 miles, but the Uelle follows a more circuitous course to the north, bending round in the shape of a great bow. The altitude of the Uelle, which at Bomokandi is 2034 feet, is found at Amadi to be 2240 feet, and the fall of the river therefore is a little more considerable; moreover, at the rapid of Panga is a waterfall, though of no great size. I have been informed from reliable sources that the waterfall is formed by a diabase-dyke 100 feet wide, striking W.N.W. and E.S.E. I was unable to verify this interesting point, or to gather more details about it, as I had to follow another route.

Nearer Amadi, granite is in evidence, forming several rapids in the vicinity.

## The Iron-Mountains of the Uelle.

### Amadi—Poko.

At a distance of about 15 miles from Amadi we came across an important group of hills, the principal being Mount Angba, situated on the right bank of the Uelle. North of Mount Angba is Mount Lingwa; southward, but across the Uelle, are seen Mount Mandjana and other minor hills.

The altitude of Mount Angba (by hypsometric observation) is about 2867 feet above sea-level, the summit being nearly 650 feet above the level of the river. The eastern face is, in its upper portion, rather abrupt. On the south and south-west, the slope is also very steep. North-westward, the ground falls away more gradually, and northward extends towards Mount Lingwa in the shape of a long ridge.

The mountain is an enormous mass of iron-ore, stretching for a couple of miles in length in a north-and-south direction, by about half a mile in width. Near the top immense beds of hæmatite are laid bare, in a series of layers resting on edge, and several hundred feet thick. The strike is N. magn. to  $20^{\circ}$  W., and the dip  $60^{\circ}$  to  $70^{\circ}$  westward. The rocks on the top appeared to affect the compass.

This group of hills, comprising Mounts Angba, Lingwa, Mandjana, and others, has somewhat the shape of a range, not well-defined, but extending apparently in a southerly direction towards Poko. Hills of similar nature situated between the Uelle and the Bomo-kandi lead us to suppose that the range may be continuous as far as Poko, where Mount Madjema, another iron-ore mountain, is also to be seen. The iron-ore met with in this group is mostly a massive black hæmatite, and appears to be very similar to the iron-ore found on Mounts Gaima and Tena (see pp. 648, 651).

Eastward of Mount Angba, a few miles farther on, granite reappears at a rapid on the river, and so it seems probable that the iron-ore beds of Mount Angba are interstratified with the crystalline series, but no direct evidence of this could be gathered. By the overland route, passing a few miles north of the mountain, on the ridge that extends towards Mount Lingwa, the only rocks observable are layers of hæmatite and large stretches of limonitic puddingstone.

### Niangara—Ndoruma.

Past Suronga, which has an altitude of about 3260 feet, and towards Niangara, the rocks are of metamorphic type. The rapid called Naka is formed by a band of quartzite, striking north and south, with a slight westerly dip. At a stream called Kitali, not very far west from Niangara, we noticed mica-schist also trending north and south. At Niangara the altitude of the Uelle River is 2230 feet.

North of Niangara is a very flat country, devoid of hills and



but slightly undulating. To show the slight difference of elevation in that part, the altitudes of the different stations may be quoted, as follows:—Niagara, 2360 feet; Bafuka, 2460; Ndoruma, 2500; Yakuluku camp, 2430; and it may be here mentioned that the three last-named places are almost on the apex of the watershed between the Nile and Congo Basins. This *divortium aquarum* does not present, however, the aspect of a more or less definite ridge, but rather of a monotonous plain or level plateau, where the many tributaries of both basins intermingle their springs and courses into an inextricable network.

According to the seasons, which here become well defined, the country, in the dry period of the year, is so parched and dry, as to be often waterless over large tracts; while, in the rainy part of the year, it becomes extremely marshy, on account of the predominantly-argillaceous character of its subsoil, and the watercourses, having very little fall, are then expanded into enormous swamps.

Little geological information is to be gleaned from this zone, clay appearing to constitute most of the subsoil, but being frequently overlain in its higher parts by limonitic rocks. Near Bafuka two ridges of the limonitic formation were seen striking north and south.

Towards Tambura, to the north of Ndoruma, the country becomes hilly again, and the watershed is more distinctly defined by large outcrops of gneiss of markedly-foliated structure, apparently dipping south-eastward at a low angle. In these gneisses I have noted, as accessory minerals, garnets, a little tourmaline, and some pale-green crystals of kyanite; black flakes of mica were also abundant.

### The Mount-Bundukwa Group of Hills.

Travelling eastward from Ndoruma, a little to the south of the border, we reached the knot of hills, situated near long.  $29^{\circ} 10'$  east and lat.  $4^{\circ} 23'$  north, comprising Mount Baghinze in the Bahr-el-Ghazal, and Mounts Bundukwa, Nangango, and Yambili, on the Congo side of the frontier. Between Ndoruma and here, the intervening country presents no hills, only large undulations, forming the shallow valleys of the tributaries of the Uelle.

Clay and limonitic puddingstone were here the only rocks met with, as far as Yakululu. Some 12 miles east of that place, appears the group of the Bundukwa Hills, a possible remnant of what may have been once a mountain-chain, ranging north-west and south-east, and perhaps connected with hills of a similar nature situated in the Nile Territory.

Looking eastward from the top of those hills, one can see that the country resumes its monotonous aspect of a level plain without any noticeable elevations.

Mount Bundukwa (3225 feet above sea-level) itself is about a mile and a half in length in a north-westerly and south-easterly

direction, by half a mile in width. Its elevation above the neighbouring plain is nearly 600 feet. The plains surrounding these hills are thickly clothed in underwoods of brush and scrub, but the greater part of the mountains is bare of all vegetation, as generally are most granitic peaks.

The formation is a strongly-foliated gneiss, the laminæ of which show much contortion and crumpling. Bands of quartz, of black mica, and others of more felspathic nature, alternate successively one with the other in many places. The strike of this formation varies between  $30^{\circ}$  and  $50^{\circ}$  W. of N., but may be said to average a north-westerly and south-easterly direction. At the top of Mount Bundukwa the dip is  $80^{\circ}$  to  $85^{\circ}$  south-westward, but at the foot of a cliff on the north side, and nearer the level of the plain, we found the beds less steeply inclined, dipping there only  $55^{\circ}$  to  $60^{\circ}$  south-westward.

The rocks found at Mount Bundukwa offer an element of interest, in having enclosed within them large crystals of kyanite. Occasionally, garnets and tourmaline were also noted in the rocks.

Mount Yambili, situated next to Mount Nangango, and about  $2\frac{1}{2}$  miles east of Mount Bundukwa, is identically of the same nature as the preceding, but on its western side we found at the foot of the hill blocks of granite formed of large elements, and from those blocks specimens of mica in slabs 4 to 5 inches square were obtained.

The plains surrounding the hills are mostly made up of alluvium, with here and there small rocky outcrops of a character analogous to those observed on the bigger hills.

### Bomokandi River—Mount Tena.

Going up the Bomokandi River from Poko to Rungu, granitic rocks are seen at two rapids situated between these two localities, but no strike can be noted.

East of Rungu the road follows a swampy tract of land on the northern bank of the river. About 20 miles west of Mount Tena, granite appears before one reaches the mountainous group. Here, Mount Tena forms a prominent feature of the landscape, rising to a height of 4900 feet above sea-level. The mass of the mountain is about 3 miles in length from north-west to south-east, and a mile in width. Its northern extremity is prolonged north-westward by a series of hills, of lesser elevation, towards and up to Mount Negbada. Mount Tena at its crest forms a succession of three rocky summits trending in the axial north-westerly and south-easterly direction, the central summit being slightly the highest. At the foot of Mount Tena iron-bearing rocks only are in evidence, and the whole mountain is a mass of iron-ore. Near the top appears an enormous outcrop of massive hæmatite, with magnetite disposed in beds striking north and south, and dipping westward about  $80^{\circ}$ . On the east side the slope is precipitous, and presents the aspect of a cliff formed by the outcrops of iron-ore.

### The Limonitic Conglomerates.

In travelling through the Uelle district, the observer cannot fail to be impressed by the enormous development of limonitic rock. As soon as one leaves Buta and the Rubi basin, this rock is most frequently seen in isolated blocks or sheets of a dark-brown colour, of medium hardness and density. The constituent elements seem to be rounded lumps of iron-ore with clayey impurities, cemented together by oxide of iron. Frequently, small pieces of rounded quartz were seen embedded in the matrix, as well as sand.

Without in any way exhibiting a stratified appearance, the rock nevertheless offers the aspect of being in many places of the nature of a sedimentary deposit. Its thickness nowhere exceeds 30 feet, and probably averages in most places from 6 to 10 feet only.

Nearly the whole of the country north of the Uelle presents to view no other rock. In the southern part it is constantly seen in patches on the rises of the undulating country.

It is a noticeable fact that the mountainous region of Arebi is, in its hilliest part, comparatively free from limonitic conglomerate, and that this is more abundant on the lower elevations, especially below the Mount-Angba hills and Mount Tena.

At the base of Mount Tena and in the vicinity is an exposure of limonitic conglomerate which deserves special mention. It covers an area which may be described as the more level ground adjoining on the south and west. It is not seen on the north or east side. This conglomerate has the aspect of a surface-formation deposited horizontally, of no great thickness (probably here not exceeding 30 feet). It is composed of large waterworn fragments, irregular in size and shape, but of identical nature with the iron-ore found in beds at the summit of the hill, and cemented together by oxide of iron.

This superficial formation is no doubt the result of the work of denudation and erosion of the iron-ores of the mountain, and its peculiar appearance here has suggested to me the possibility that all the limonitic rocks found so abundantly in the Uelle are the product of denudation and erosion of iron-mountains such as have just been described, or even of other iron-bearing veins, perhaps at present covered up. The work of redeposition took place at a time when the Uelle Basin may have been more or less a succession of shallow lakes and vast swamps. Then the alteration and redistribution of the ferruginous materials would have been attended by every condition favourable to the formation of such limonitic deposits. After being deposited over extensive tracts of country, the limonitic conglomerate has been removed by erosion along some of the water-courses, and this accounts for the formation being invariably found upon the summits of the gentle undulations. The process of formation of these conglomerates is not yet at an end, and in close proximity to the iron-mountains it is still in operation.

In presenting this view of the possible origin of these limonitic conglomerates, I wish it to be understood that it appears to me

to be the simplest hypothesis that could suggest itself, from the geological aspect of the country, but that as yet too little information is available, and my observations are too incomplete, to advance more precise conclusions.

No fossils have been found in these limonitic conglomerates, so far as I am aware.

A practical aspect of their occurrence is that they constitute an excellent material, always ready to hand, for the making of hard roads. This should be of importance to the Congo State Government, who are, I believe, now engaged in constructing such roads.

The superficial limonitic formation described is not exclusively confined to the Uelle district, and similar rocks are found in many parts of Africa, on the western coast, and in most districts of the Congo. Referring to the Katanga, and quoting the eminent authority of Dr. E. Dupont in support, the learned geologist Cornet describes it as follows<sup>1</sup>:—

‘These deposits are generally of a yellowish-red or brick colour, due to a large proportion of hydrated oxide of iron. It is this hydrated oxide of iron which, in concreting in the mass of the material, principally near the base, gives rise to beds, lumps, or nodules often embedding rolled pebbles in a sort of impure limonite of cellulous and scoriaceous aspect. The proportion of iron contained is often sufficient to allow of its being used as iron-ore by the natives. Where the superficial action of water has taken off the soft parts of the deposit, the scoriaceous limonite appears in isolated blocks on the surface, or constituting floors often of considerable extent.... This scoriaceous limonite is more especially found where the subsoil is made up of practically-impermeable rocks.’

Dr. Cornet gives the name of ‘red deposit’ to this formation in the Congo, and remarks, very justly, that its only point of resemblance to typical laterite lies in the possession of a brick-red colour.

### Arebi—Mount Gaima.

The south-eastern portion of the district, comprised between the Uelle-Kibali and the Bomokandi Rivers, forms a hilly and even mountainous country with Arebi for a centre, averaging in altitude nearly 3000 feet. At the headwaters of the Uelle-Kibali, near Lake Albert and the Nile Territories, the ground is still higher, and there probably exceeds 3600 feet in average altitude. This hilly zone appears to be entirely granitic in nature, and some prominent mountains, such, for instance, as Mount Tiberi (4210 feet above sea-level), are solid masses of granite. The whole extent of country west of Arebi towards Gumbari, and north towards Mount Combe, is granitic. Nearer Arebi, a little farther north, rocks more basic in appearance are occasionally met with. At the junction of the Motu and Arebi rivers a phyllite was observed, in a small outcrop striking north-north-west and south-south-east, with an easterly dip.

<sup>1</sup> Ann. Soc. géol. de Belg. vol. xxi (1892-94) Mém. pp. 230 & 231.

Farther north, near Vankerckhovenville,<sup>1</sup> and on the Uelle-Kibali, Mounts Gaima and Yagu present some points of interest in their great analogy of structure with Mount Tena, iron-ore beds being also much in evidence. (See fig. 1, p. 652.)

Mount Gaima (3960 feet above sea-level) is situated about 8 miles west of Vankerckhovenville, and is quite close to the Uelle-Kibali River. Similarly to Mount Tena, it presents in its upper part great beds of iron-ore striking north-west and south-east, but here the dip is easterly at an angle of 54°. These ferruginous beds appear to be underlain on the west side by a diabasic rock, and are probably interstratified with it. At the base of the hill, near the river, and on the east side, the ground is thickly covered by a bed of pebbles, of the same nature as the iron-ore met with on the top; but no conglomerate is to be seen, and the pebbles are not cemented together.

The iron-ore of Mount Gaima is a hæmatite of very dense character. The beds are magnetic on the summit.

Mount Yagu (4400 feet above sea-level) is a few miles farther to the south, and has also a stratum of iron-ore near its summit. The strike here is east and west, and the dip northerly. The difference of strike and dip from those observed on Mount Gaima points to local displacement of the beds. The thickness of the iron-ore formation here was estimated at 200 or 300 feet; it was observed on the northern face, where the rocks form a precipitous cliff.

The natives of that part procure their iron for making knives, spears, etc. from this mountain, at a spot where the ore is much softer than elsewhere, and brittle. In their primitive attempts at mining they have dotted the hill-slopes round about with many shallow pits, the biggest being hardly wide enough for a man to crawl into.

From Vankerckhovenville to Dungu a kind of phyllite covers a fairly-wide extent of country, being first seen at Dungu, and then at the Rapids of Makassa and in places as far as the River Obu.

In the neighbourhood of Vankerckhovenville itself outcrops of diabase were met with.

#### Vankerckhovenville—Farach.

In travelling in a north-easterly direction, towards Farach, a small outcrop of gneiss was met with between the Uelle-Kibali and the Nzoro Rivers, striking north and south, and dipping about 11° eastward. Farther on, a small hill, situated about 10 miles north-east of Vankerckhovenville, forms an outcrop of diabasic rock. Thence onward to Farach the country becomes almost level, and offers to view only some granitic rocks, specimens of which were obtained at the Rivers Kwado and Aro respectively, and also between the Nzoro and the Uelle-Kibali Rivers.

<sup>1</sup> VKH on the map (Pl. XLII), just across the Nzoro River from Mount Gaima.

Fig. 1.—Sketch to illustrate the possible relationship between the iron-ore beds of Mount Tena and Mount Gaima. (See p. 651.)

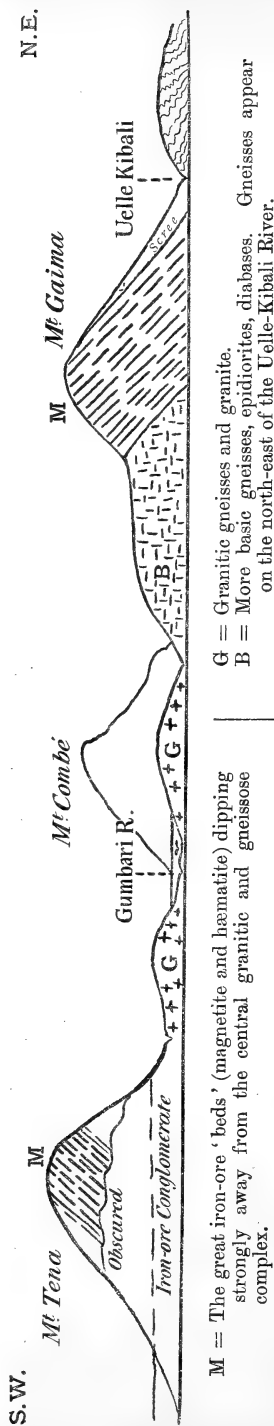
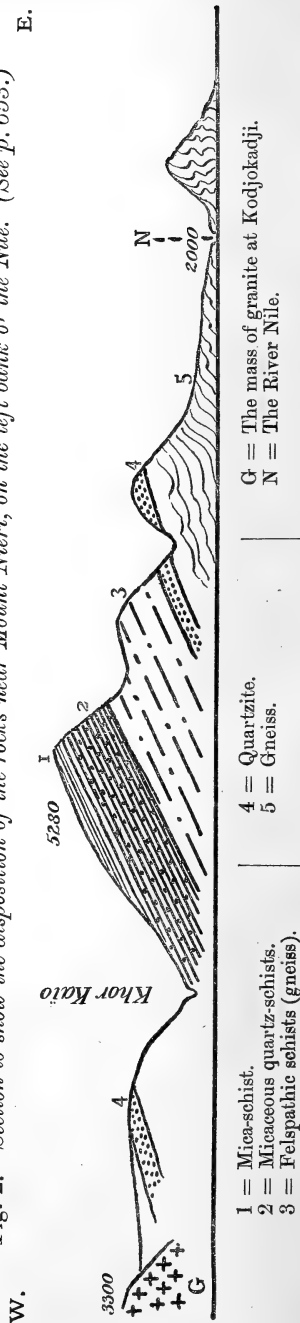


Fig. 2.—Section to show the disposition of the rocks near Mount Nieri, on the left bank of the Nile. (See p. 653.)



## The Nile Territory (Lado Enclave).

The basin of the Uelle rises gradually up to the watershed dividing it from the Nile Basin. At its highest point, which is situated a little farther east than Aba, I came across granitoid gneiss.

Travelling eastward, up to Loka, patches of gneiss are the only rocks in evidence. At Loka, Mount Gumbali, the highest summit of that neighbourhood, reaches an altitude of 5730 feet above sea-level, being 2450 feet above the surrounding country, and the mountain appears to be wholly built up of granite. It is a mountain with a double summit, of which the lower dome, under the influence of weathering, has peeled off near the top in such a way that, seen from Loka, the shape bears some resemblance to a Roman helmet.

Going in a southerly direction from Loka, the ground is found to become considerably lower, and, at the crossing of the valleys of the

Fig. 3.—Section parallel to that shown in fig. 2 (p. 652), but farther north, at Mudi.



[For explanation, see fig. 2, p. 652.]

Kidju and the Kaia whole series of gneisses and metamorphic rocks are met with, striking nearly due north and south, and undulating with the country.

Towards Kodjokadji the country is again higher and more granitic in character, and forms a small plateau bordering on the Nile. This plateau breaks into the Nile Valley by two successive ridges, ranging north-west and south-east, built of highly-crystalline rocks. The Nile Valley all along these ridges narrows down extremely, and the river is interrupted by innumerable rapids.

In the valley itself, and near the Nile, the predominant rock is gneiss, exposed in nearly-vertical beds. These, as we proceed from east to west, are seen to alter their dip gradually into a more horizontal position, until, approaching the summit of the ridges, we find some quartzites and mica-schists dipping south-westward at an angle of only  $25^{\circ}$  to  $30^{\circ}$ . This formation strikes  $40^{\circ}$  W. of N., averaging nearly north-west and south-east, and is both regular and persistent.

The valley of the Nile along this mountainous ridge has an altitude of between 1800 and 2000 feet (above sea-level).

Lower down the Nile, towards Redjaf, several dykes of a species

of basic andesite appear to cut through the gneiss in a south-westerly and north-easterly direction. At Redjaf, the mount of that name is an isolated hill of gneiss, rising about 300 feet above the level of the Nile.

Returning from Redjaf towards Loka, one crosses the Dinkala Hills, a granitic group of some importance. From these hills to Loka, bands of metamorphic rocks were observed, striking very regularly north-west and south-east.

#### IV. SUMMARY.

The Uelle district (leaving aside the small portion described as forming the Rubi Basin, where the rocks are of more recent formation) consists entirely of an area covered by the very shallow and broad basin of the Uelle River and its tributaries. This long belt is of great geological uniformity, and its whole substratum appears to be granitic and metamorphic.

The granite met at Libokwa, and also that found in the zone of Bima-Bomokandi-Zobia, seems to be of normal type; but, in the absence of specimens, it is difficult for me to attempt to class it definitely. As, however, at the station of Libokwa we noted an isolated block of true gneiss, this would point to the rocks of the whole district having undergone dynamometamorphism.

Towards Mount Angba the country becomes distinctly and entirely metamorphic in character. North of Ndoruma, as well as at Mount Bundukwa, the rocks also are all metamorphic, a fact which leads one to infer that the entire country lying north of the Uelle, although offering to view only alluvium and limonitic rocks, is close to its surface underlain by metamorphic rocks of the same nature.

Recent eruptive rocks, so far as I have been able to ascertain, are apparently very rare.

In the south-eastern mountainous portion of the Uelle district, rocks of a more basic composition are as a rule prevalent, and may be said to form an intrusive mass, on the margin of which abut the iron-ore beds of Mounts Tena and Gaima. These beds were probably upthrust by the underlying diabasic rock, as seen on Mount Gaima.

The close resemblance of the iron-ore of Mount Tena with that of Mount Gaima suggests the possibility that both may have belonged at one time to the same formation, subsequently disrupted by the intrusive mass.

Throughout the Uelle district the abundant argillaceous deposits represent the ancient alluvial formations, and to some extent also the decomposition *in situ* of the granitic rocks so prevalent everywhere in the district. The frequent occurrence of the limonitic rocks probably also bears some relation to the numerous iron-ore hills existing in the district, as already pointed out. Both these formations are evidently of comparatively-recent date.



In the Nile Territory the rocks are all more or less metamorphic, but the country shows here and there peaks of granite (such as Mount Loka, the Dinkala Hills, and Kodjokadji) piercing through the stratified series of gneiss, quartzites, and mica-schists.

Recent eruptive rocks are comparatively rare, such being found only at Redjaf. These are dykes of basic andesitic rock, which intersect the gneissose series.

Similarly to the greater part of Equatorial Africa, this area appears to be devoid of fossils, although it is possible that further and more competent search may yet reveal some.

It will be seen that the foregoing observations tend to confirm the views already held as to the geological features of this portion of the Congo Basin; the granitic and metamorphic primary rocks are present across the whole country from east to west and from north to south, uncovered by any other rocks except the alluvial clays and sands and the nearly-related ferruginous rocks; the grey and red sandstones, so prominent in the regions lying west, south, and east of the Uelle Basin, are conspicuously absent.

#### V. PETROLOGICAL NOTES. By J. ALLEN HOWE, B.Sc., F.G.S.

##### Rocks from the Neighbourhood of Buta.

Specimen No. 48.<sup>1</sup>—This is a fine-grained, chocolate-coloured, laminated mudstone containing minute flakes of mica. There is no trace of any fossil, unless one or two microscopic pellets may be taken to represent coprolites.

No. 42, Rubi River.—From large blocks apparently embedded in the clayey alluvium of the river.

It is a compact cream-coloured rock, with well-marked oolitic structure. In the thin slice, opaque, dull, spherical grains are seen in a fairly-large amount of granular crystalline calcite, which forms the matrix. The grains are fairly uniform in size, and all possess a well-defined concentric structure; there is no trace of any radial structure, and the material is too dusty in character to give a cross in polarized light. The centres of the grains are usually filled with more or less clear granular calcite, and no organic or elastic bodies have been noticed in them. There are several compound grains, one large grain enclosing one or two smaller ones. (See Pl. XLIV, fig. 2.)

The rock is suggestive of an oolite formed from a calcareous spring, but there is nothing to show that organisms have taken any part in its formation. In places the rock includes small pellets of grey clay [52], and where this is present the limestone tends to assume a stylolitic structure.

<sup>1</sup> These numerals refer to the microscope-slides and rocks deposited in the Museum of Practical Geology, Jermyn Street, London.

No. 51.—This specimen, said to be from the same locality as the preceding, is a compact rock of slightly-redder colour; in the hand-specimen it shows the spherical oolitic grains weathering more readily than the matrix, but in the centre of each grain a little heap of yellow granules stands up above the rest. In the thin section the round grains are observed to be slightly smaller than those in No. 42, and the majority of them are almost perfectly spherical; there are no cases of composite grains.

The concentric structure characteristic of No. 42 is absent, and instead there is a markedly-radial arrangement of alternating clearer, crystalline, and obscure, dull rays; the latter are generally conical in section, with their bases on the periphery of the grain. The ratio of clear to dull matter is remarkably constant; the clear matter is always granular calcite, and in no case has any fibrous radial calcite been observed. (See Pl. XLIV, fig. 1.)

In the centre of each grain are irregular granules or small rhombs of a yellowish carbonate, probably chalybite; these are not strictly confined to the centre, but to some extent appear sporadically within the mass of the grain as well.

In portions of the slide many of the spheres have been partly obliterated by the crystallization of the calcite of the groundmass, which is usually clear and granular, although a few small flakes of hæmatite are occasionally included in it.

The structure of these spherical grains strongly suggests an organic origin for them; but there can be no doubt as to the inorganic nature of the other oolitic limestone, of which this appears to form a variety.

### Rocks of the Archæan (?) Series.

The granitic district including the country between the Lipodongu Falls and Poko, between Bima and Amasi, and the granite-ridge between the Rubi and the Uelle Rivers.

Granites of a similar type were observed to form the substratum of the whole of this district and, with the exception of the diabase reported from Panda, no other kind of rock was found beneath the alluvium. Only two specimens were brought back: No. 54 from the rapids on the Rubi River, where it cuts the granite-ridge; and No. 52 from a point some 60 miles farther east, near Poko.

No. 54 (granite-gneiss) is a dark rock of medium grain; the colour is due to the red staining of the feldspars and the abundant spots of mica. The microscope shows feldspar in fairly-large, hypidiomorphic crystals, much decomposed and stained with iron-oxide; granular epidote and chlorite are common in the feldspar-mass, as alteration-products. Both plagioclase and orthoclase are represented. Quartz occurs in broad streaks and grains, and it nearly all shows undulose extinction. A greenish mica is the remaining important mineral. A little hornblende is now

represented by chlorite. Sphene and apatite are present in grains of moderate size; magnetite is prominent in large irregular masses.

No. 52 (granite-gneiss).—A medium-grained rock, showing dull greenish and dull pink-stained feldspar, with abundant dark grains of mica.

In sections the rock is seen to be principally made up of large idiomorphic or nearly-idiomorphic feldspars; the bulk of this appears to be orthoclase, but some plagioclase is present. All these large crystals are extremely altered, giving rise to a mixture of epidote, in short stout prisms, muscovite, chlorite, zoisite, and actinolite.

Mica of a dark-greenish colour is abundant. Hornblende is only doubtfully present. Epidote and leucoxene appear in patches. Most of the quartz occurs as granules between the feldspar-xenocrysts, and it is frequently associated with a later crop of feldspars in clear granules.

The above-mentioned rocks have so many points of similarity that it would seem to indicate that in this large area we have to deal with a massif of great uniformity; for, although no other specimens have been examined, the granite from the whole region is reported to be quite similar in character.

### The District about Arebi.

This region includes the country between the Uelle-Kimbali on the east, and the Gadoa River (a tributary of the Uelle) on the west, and lies north of the River Bomokandi. It includes Mounts Tena, Gaima, Yagu, Tiberi, and Combe.

The specimens from this district are Nos. 10, 11, 12, 13, 17, 21, 34, 35, 36, 37, 39, 40, 41, 44, 44A, 53, & 56.

No. 41, from the summit of Mount Tena.—A massive, finely-granular iron-ore.

No. 40, from the conglomerate at the foot of Mount Gaima.—A pebble of massive, finely-granular hæmatite-ore, similar to material at the summit of the mountain.

No. 10, from the top of Mount Gaima.—Massive magnetite, with hæmatite.

No. 11, from the top of Mount Gaima.—The rock has the appearance of an irregularly-laminated (? shearing-structure) iron-bearing sandstone or quartzite, weathering on the edges into honeycomb-structure.

It consists of finely-granular quartz and iron-oxides (magnetite), the latter occupying a large proportion of the rock-mass. The quartz-grains are very uniform in size, except in the small veins which intersect the rock, the grains in these being rather larger.

No original clastic structures are visible, and probably all the quartz has recrystallized. Where the massive ore is absent a red iron-oxide staining surrounds all the quartz-grains.

No. 12, Mount Yagu.—A foliated quartz-iron-ore schist, similar to 13, described below.

No. 13, hill south of Mount Combe.—A fine-grained iron-bearing quartz-schist. A few streaks of magnetite run through the slice, and small crystals of the same are scattered evenly throughout the whole rock: in addition, there are numerous minute crystals of hæmatite which are generally isolated, but in places are aggregated into small masses.

No. 53, Mount Tiberi (microcline-granite gneiss).—A pale granitic-structured rock, of moderately-coarse grain, showing dull-white felspar, clear felspar, and quartz. Muddy-looking hypidior-morphic feldspars, often with a narrow clear margin, are set in large plates of microcline. The clouded felspar appears to be mostly oligoclase, the alteration-product being principally mica. Quartz occurs in patches and blebs within the microcline. Green chlorite-patches probably represent hornblende, and are quite subordinate in amount. Epidote, sphene, and apatite are present.

Microperthitic structure is seen in some of the microcline.

No. 36, Mount Combe (microcline-granite gneiss).—A fairly coarse-grained rock, with pale-green felspar, white felspar, quartz, and hornblende.

The slice shows phenocrysts of orthoclase and oligoclase, with clouded centres (micacized and epidotized) and clear fresh borders.

Microcline is abundant in large plates, enclosing the quartz and felspar. Epidote is common in grains within the altered felspars, and also associated with hornblende. The latter mineral is in idiomorphic green crystals and plates; chloritic alteration appears in places. Quartz is present in large irregular plates between the felspars. Apatite in stumpy crystals, magnetite in small grains, and leucoxene in patches also occur.

No. 35, Mount Combe.—A pale-greenish rock with dark spots. Very similar to No. 36. Idiomorphic orthoclase, and probably oligoclase and andesine, occur in short prismatic crystals with mica, epidote, and zoisite as alteration-products in their cloudy bodies. Microcline (and perhaps orthoclase) encloses the older felspars, and also includes small round blebs of quartz. Quartz also occurs in somewhat large plates with polysynthetic structure. Green hornblende is present, usually idiomorphic. Epidote is frequently associated with the hornblende. Sphene occurs in large masses, and apatite in small prisms. Magnetite in cubes generally accompanies the hornblende.

No. 34, Mount Combe.—This rock is almost identical with Nos. 35 & 36.

No. 21, from a point south of Mount Gaima.—This is part of the same gneissic mass as Nos. 34, 35, & 36. The amount of sphene is considerable.

No. 35 A, Mount Combe (diabase).—A dark greenish-grey compact rock, of medium grain.

The section shows much pale-brown augite in ophitic relationship with the feldspar. The feldspar is moderately fresh, but is spotted with dusky alteration-products. The crystals are stout, lath-shaped; Carlsbad and albite-twinning are both common, most of it is near labradorite. A little fresh feldspar and some quartz occur with occasional micrographic structure between the larger feldspars. Iron-ores are in irregular grains and skeletons.

No. 44, Arebi.—A dark-green, coarse-grained rock, with hornblende greatly predominating; dull feldspar and quartz occupy the spaces between the crystals. The green hornblende is in large plates and idiomorphic crystals; the plates enclose flakes of biotite, the idiomorphic hornblende, and some olivine in a poecilitic manner. All the feldspars are greatly altered, micacized. Quartz appears in patches of fair size, enclosing the feldspar and a few needles of actinolite. Some granular epidote occurs in the altered feldspars. A colourless amphibole is present in small irregular patches.

The rock might be regarded as a hornblende-gabbro, and in appearance it is not unlike an olivine-poor hornblende-picrite.

No. 44 A, from the Arebi District, several miles north of No. 44 (sheared diabase).—A pale-greenish rock, evidently much crushed and slightly foliated, with shiny surfaces along the direction of foliation.

The thin slice shows a highly-altered rock, apparently a sheared diabase. The shearing is not very evident in the section, and many of the feldspars retain their form. A very fine epidote-dust is prevalent; calcite, talc, and chlorite are also present.

No. 17, near Vankerckhovenville (gneiss).—A fine-grained greenish-grey rock, consisting chiefly of well-foliated granular feldspar and quartz.

No. 37, near the confluence of the Motu River with the Arebi.—A dull-green rock, compact and slaty in appearance, slightly shiny on fresh surfaces; weathering brown. The thin section shows a fine-grained feltwork of chlorite with granular quartz; the whole is liberally sprinkled with small crystals of pyrites and some magnetite.

A phyllite or fine-grained chlorite-schist.

No. 39, south of Vankerckhovenville (felspathic chlorite-hornblende-schist).—A pale greenish-grey rock, with dark spots, of a compact fine-grained texture.

The bulk of the rock is composed of a granular aggregate of felspar, with a subordinate amount of granular quartz. The dark spots noticed in the hand-specimens are crushed and distorted green hornblende-crystals. Minute flakes of chlorite are abundant throughout the rock, and exhibit a regular orientation. Very small granules of epidote are common.

### Rocks from Dungu and the Makassa Rapids.

From the Makassa Rapids on the Uelle, midway between Dungu and the mouth of the Obu River, three specimens were obtained. Two of these, Nos. 18 & 19, may be called phyllites, the other rock, No. 20, is a gneiss.

No. 18, Makassa Rapids (phyllite).—A compact greenish rock, with marked undulose schistosity, and shiny surfaces when freshly broken. The slide exhibits fine granular quartz, with abundant streaks of talc and mica. Much granular calcite is present. Throughout the rock small plates of chlorite are regularly scattered. Groups and individual minute needles of rutile are common.

No. 19, Makassa Rapids (phyllite).—This rock is similar in appearance and composition to No. 18. A number of dark iron-stained crystals are seen in the thin section; they probably represent decomposed pyrites.

These two rocks may possibly represent altered calcareous shales. Similar rocks were noticed at Dungu.

No. 20, Makassa Rapids (granulitic microcline-gneiss).—A pale, fine-grained, foliated rock.

The bulk of the rock is composed of a granular aggregate of quartz and clear felspar. Ill-defined masses of micaceous feltwork with epidote-granules are abundant; epidote and sphene occur in small grains. Included in the granular matrix there are broken crystals of microcline and plagioclase, and larger grains of quartz; strain-twinning and undulose extinction are common.

### Rocks from between Vankerckhovenville and Farach.

No. 14, between Vankerckhovenville and the River Kwado (diabase).—A fairly coarse-grained rock, with a reddish tinge.

Large hypidiomorphic prisms of plagioclase, mostly near labradorite, are somewhat clouded; pericline and albite-twinning occur together frequently. Moulded upon the felspar in an ophitic

manner is an altered augite, in large masses, generally with bright green actinolitic reaction-rims. Large masses of iron-ore are present; they are usually surrounded by a zone of granular garnet which, in its turn, is often bounded by a fringe of hornblende. Occasional grains of epidote are present, as well as flakes of hæmatite.

Nos. 15 & 16, between the Rivers Kwado and Aro (microcline-gneiss).—These are two similar fine-grained gneisses. Microcline in abundant large plates is the predominant feldspar; there is also some plagioclase. Quartz occurs in irregular grains and as bleb-like inclusions in the microcline; fluid-inclusions are common in the quartz. Both a colourless and a dark-brown mica are present. Epidote is plentiful in rather large pale masses. Zircon and sphene are present; also small patches of chlorite in association with the mica.

The foliation is well marked, even in the slide, and is accompanied by an approach to granulation and a sort of mortar-structure. (See Pl. XLIII, fig. 1.)

### Rocks from the Northern Boundary of the Congo, bordering the Bahr-el-Ghazal.

The specimens brought from this region were all collected in the mountain-group comprising Mount Baghinze, Mount Bundukwa, Mount Nangoro, and Mount Yambili.

Nos. 1-6, from Mount Bundukwa.—All these specimens are varieties of a very coarse pegmatoid gneiss, the several elements tending to run in distinct layers and veins. Tourmaline in stout prisms, kyanite in broad blades, and red garnets are very abundant in some layers; in some places a sort of tourmaline-rock is produced by the concentration of this mineral. Fairly large zircon-crystals have been noticed during the microscopic examination of the rock.

### Rocks from the Lado Enclave.

Three specimens have been examined from the River Kidju, at a point on the road midway between Loka and Kodjokadji—Nos. 31, 32, & 33.

Nos. 31 & 32 (microcline-gneiss).—A cream-coloured, medium-grained banded rock. The texture, as seen in the section, is granitic; there is no sign of foliation. Quartz occurs in fair-sized plates, also in blebs within the feldspar (corrosion-quartz). Streaks of dusty inclusions are common. The feldspars comprise abundant microcline, orthoclase, and plagioclase (oligoclase); albitic and periclinic twinning frequently occur together. Some of the feldspars have schiller-structure, produced by rows of negative crystals. Micrographic intergrowths of feldspar and quartz appear sporadically in small patches. A curious, dark-green, pleochroic variety

of hornblende occurs in a few patches. Biotite is present, but is sparingly represented; it is often greenish in colour. A little sphene is associated with the mica. A few small rounded crystals of zircon are present, also short prisms of apatite. (See Pl. XLIII, fig. 2.)

No. 33 (amphibolite).—A very dark-greenish rock of uniformly-fine grain, speckled with small white spots of feldspar. The foliation is made evident by the orientation of the hornblende-crystals.

Green hypidiomorphic crystals of hornblende make up the bulk of the rock. The granular feldspar is all quite fresh, and most of it is plagioclase. Quartz is present, but is subordinate.

Rocks from the Nile Valley, between Lado on the north and Dufle on the south.

With the exception of the basic dykes south of Redjaf (No. 22), all the specimens from this area are either quartz-schists, mica-schists, or microcline-gneisses. Specimens 38, 25, 43, 30, 26, 27, 28, 29, 23, & 24.

No. 27, Mount Nieri (microcline-gneiss).—A pinkish-grey banded gneiss. The thin section exhibits a granitoid texture and somewhat coarse grain. Quartz and orthoclasic feldspar make up the bulk of the rock, with flakes of muscovite roughly arranged in lines. The quartz is fairly abundant; it extinguishes with strain-shadows. The orthoclase is very fresh: Carlsbad-twinning is prevalent. In places an older, muddy feldspar occurs in small amount. Microcline is present in fairly-high proportion, as well as some oligoclase; all these minerals occur together in a coarser or finer granular aggregate. A few grains of apatite are present.

Nos. 25 & 30 from near Mudi; also Nos. 26 & 28 from the ridge north of Mount Nieri (quartz-schists and mica-schists).—These are all examples of quartz-schists, passing by every intermediate variation into micaceous quartz-schists. Nos. 25 & 30 are more micaceous than the other two, and the latter is more micaceous than the former. The foliation causes the rocks to break readily in one direction; the more quartzose forms have a very saccharoidal appearance in the cross-fractures.

No. 29, north of Mount Nieri, is a coarse, highly-micaceous gneiss.

No. 38, from near Uando, is a cream-coloured gneiss.

No. 22, dykes south of Redjaf on the Nile (basic andesite).—A black, even-textured rock. Feldspar-laths with interstitial granular augite, larger phenocrysts of anorthoclase, sometimes broken.

There is one specimen from Suronga, a brownish chert, which might have been of greater interest if it had been seen *in situ*



and in relation to the surrounding rocks, but as it was found in an isolated lump, it is not safe to do more than mention the occurrence. No fossils have been seen in the thin section of this rock.

### Summary.

The results of the examination of the rocks from the Uelle Basin and the Lado Enclave may be briefly summarized as follows:—In the extreme western part of the region, about Buta on the River Rubi, are the only 'post-primary' rocks—to use Cornet's expression—observed in the whole region; that is, if we leave out of account the chert in loose blocks found near Suronga. Nothing else has been seen that would represent the Kundulungu Beds of Cornet or the Karagwe Series of the East-African Lake-District.

From Djabbir and the Lipodongu Falls on the Rubi River, as far as Bomokandi and Poko, if not somewhat farther, granite of fairly-normal type predominates.

Farther east, mica-schists and quartzites set in, and include the remarkable iron-mountains of the central area—comprising the mountains of Angba, Mandjana, and Madjema, and the groups about Mount Tena and Mount Gaima.

In the south-eastern corner of the region examined, about the headwaters of the Bomokandi and Uelle-Kibali Rivers, there appears to be a complex massif of diabasic rock in various stages of freshness or of extreme crushing, along with microcline-granite-gneisses and chloritic phyllites.

Northward, along the boundary of the Congo State and the Bahr-el-Ghazal, a series of very coarse gneisses occurs (pegmatoid gneiss), with large mica-, felspar-, and quartz-elements and local developments rich in tourmaline, kyanite, and garnet.

From the Nile about Dufle, down the river as far as Lado, quartz-schists, mica-schists, and microcline-gneiss are the only rocks collected, with the two exceptions of the basic andesite from the dykes south of Redjaf, and an amphibolite from a point midway between Loka and Kodjokadji.

No attempt has been made in these notes to correlate the rocks with others from surrounding regions, as the necessary imperfections of the field-evidence prevent any such effort from being of much value; we have, therefore, been contented to place on record a few isolated facts, in the hope that they may be of use to future workers in this area. It may be pointed out, however, that the crystalline rocks of the eastern portion of the area described appear to be analogous in every way to the rocks of the same age in Uganda, British East Africa.

Special references were not needed, as there has hitherto been no more than a brief mention of the geology of the greater part of the district here described, but we append a short list of papers dealing more or less directly with the neighbouring areas.

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## EXPLANATION OF PLATES XLII-XLIV.

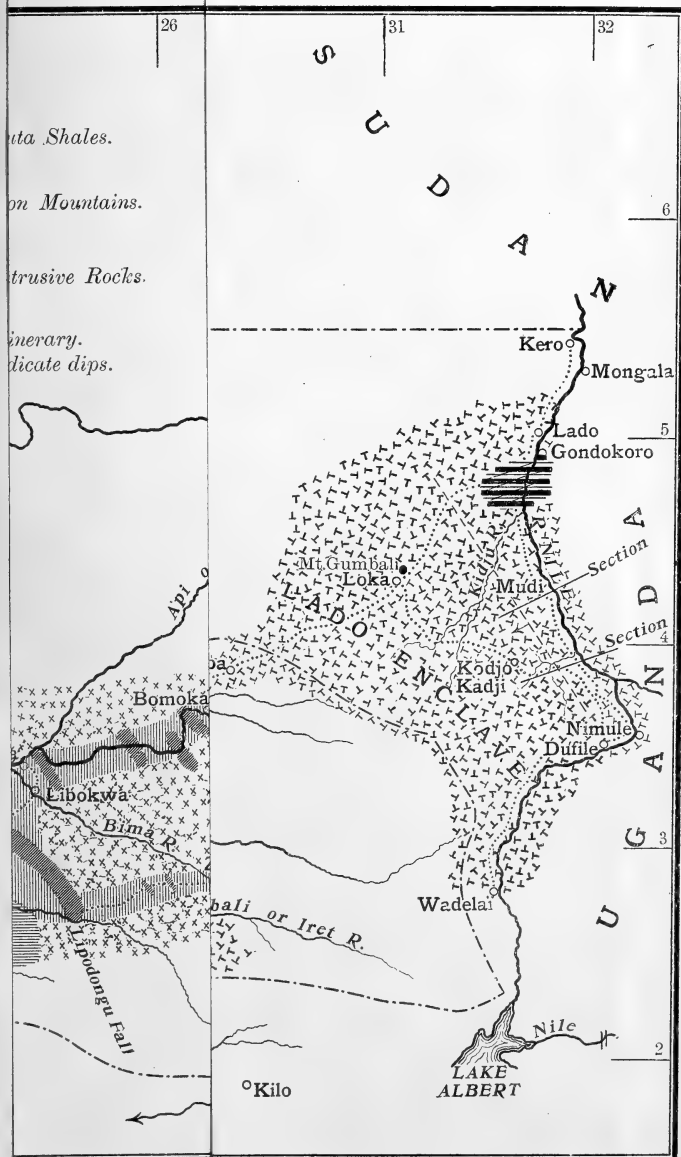
## PLATE XLII.

Geological sketch-map of the north-eastern territories of the Congo Free State and the Lado Enclave, on the scale of about 70 miles to the inch.

The signs (M), (P), (Q), (S) indicate respectively mica-schist, phyllite, quartzite, and sandstone at those points where they appear upon the map. The straight lines joining the letters N and S signify the direction of the strike.

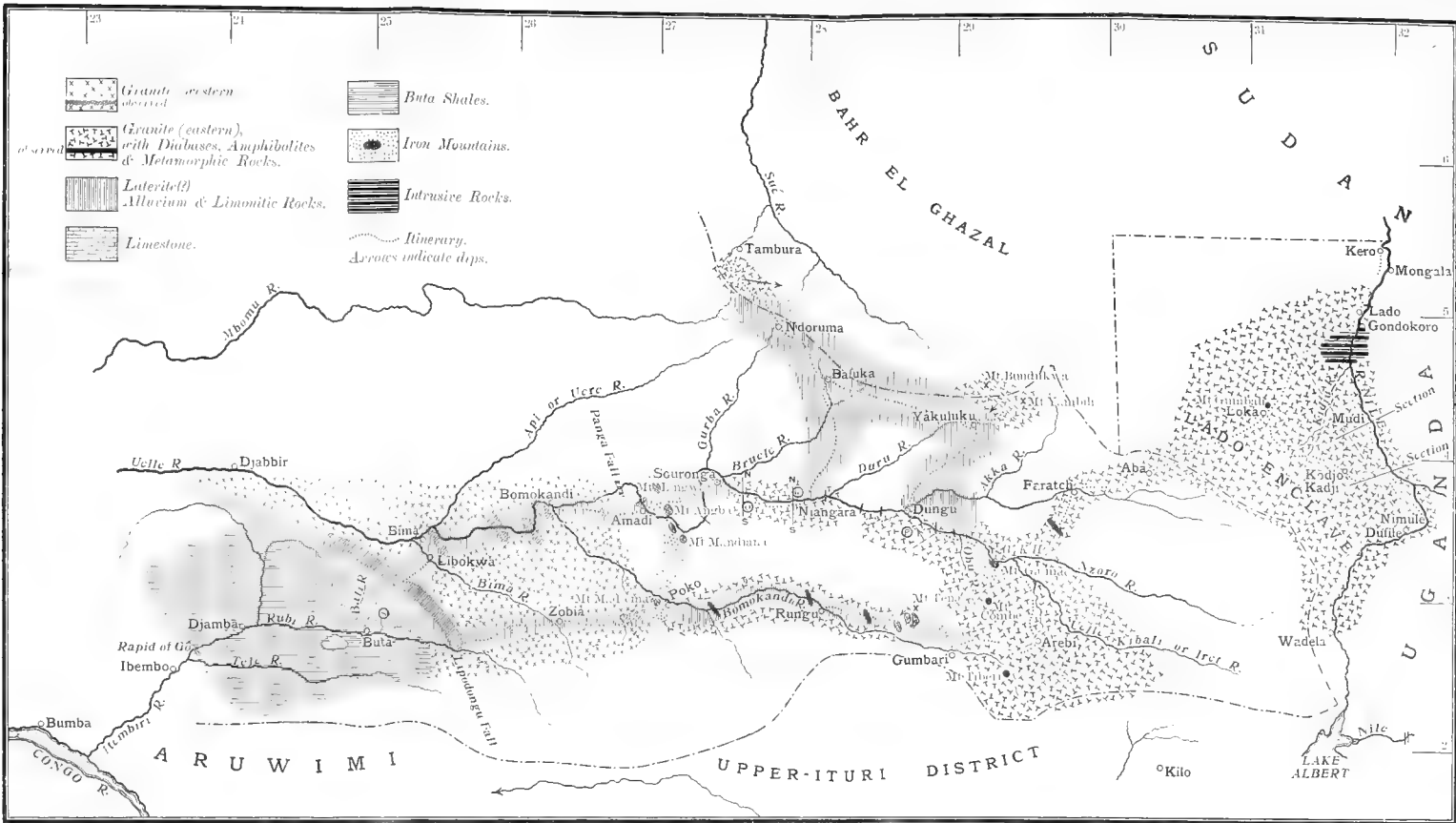
## PLATE XLIII.

- Fig. 1. Muscovite-biotite-epidote-gneiss, obtained between Vankerckhovenville and Farach. Magnified 15 diams. Specimen No. 15 (see p. 661).
2. Biotite-hornblende-microcline-gneiss, obtained between Loka and Kodjokadji. Magnified 15 diams. Specimen No. 32 (see p. 661).



MAP OF THE NONO ENCLAVE.





GEOLOGICAL SKETCH-MAP OF THE NORTH-EASTERN TERRITORIES OF THE CONGO FREE STATE AND THE LADO ENCLAVE.

[Scale : 1 inch = approximately 70 miles.]



FIG. 1  $\times 15$  DIAM.



FIG. 2  $\times 15$  DIAM.



GNEISSES FROM THE CONGO FREE STATE.





FIG. 1  $\times 15$  DIAM.

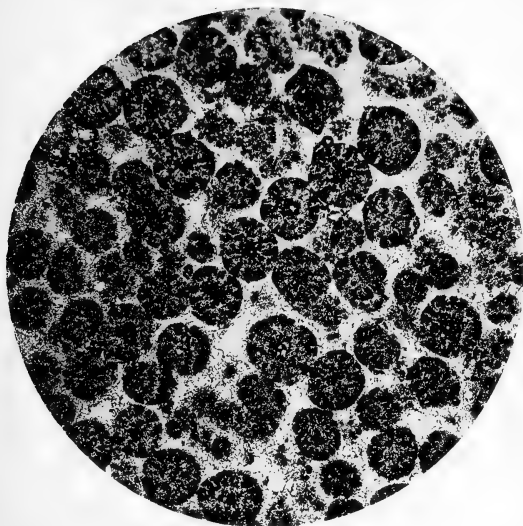
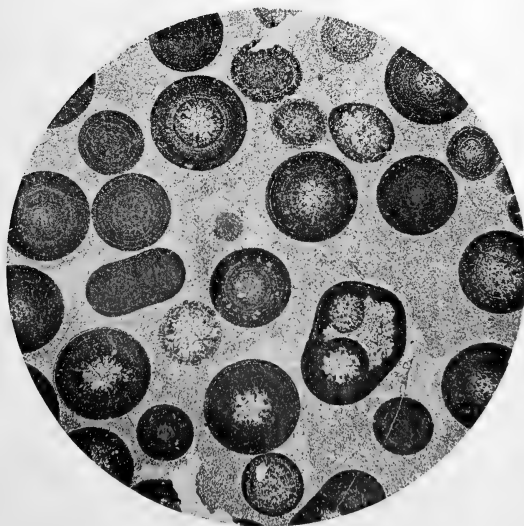


FIG. 2  $\times 10$  DIAM.



OOLITIC LIMESTONES FROM THE CONGO FREE STATE.



## PLATE XLIV.

- Fig. 1. Ferruginous oolitic limestone, from Buta, on the River Rubi. Magnified 15 diams. Specimen No. 51 (see p. 656).  
2. Oolitic limestone, from the same locality. Magnified 10 diams. Specimen No. 42 (see p. 655).

## DISCUSSION.

The CHAIRMAN (Mr. H. B. Woodward) referred to the fact that the area examined by M. Preumont extended over 70,000 square miles, in a country where a geological survey was rendered difficult, and often impossible, by the dense vegetation. Nevertheless, he had made an important and interesting series of observations, which had been ably elucidated with the help of Mr. Howe.

Mr. WALCOT GIBSON said he was sure that all interested in African geology would be indebted to the Authors for their paper on this little-known region. Once again the absence of fossiliferous deposits from Central Africa was demonstrated, from a region where it might have reasonably been expected that such would occur. This paucity of fossil evidence, on which to base the age of the dynamic and volcanic phenomena in East-Central Africa, should be kept in mind. The iron-bearing schists and accompanying rocks described by the Authors recalled a sequence in Griqualand West which, there was good reason to believe, approximated in age to the Rand gold-bearing deposits.

Mr. HUDLESTON welcomed this paper, since it supplemented the observations of Cornet and Barrat in their several descriptions of different portions of the Congo Basin. It also served to confirm, towards the north, their conclusions as to the relations between the ring of old crystalline rocks, which form the periphery of the Congo Basin, and the red-and-white grits described by Cornet under the general term 'formations post-primaires,' which fill up the vast interior of that basin. In the sketch-map which he (the speaker) had ventured to publish, a gap had been left in the line indicating the approximate limits of the red-and-white grits towards the north; and he had indulged in the hope that there might be a break in the ring of crystalline rocks towards the watershed between the basins of the Congo and Lake Chad, so that these grits might be traced into the system of the River Shari, the principal feeder of that lake. The results obtained by the Authors were unfavourable to this view, and it seemed as though the ring of crystalline rocks was as complete on the north as elsewhere.

The description of the iron-ores in relation to the plutonic massif was of great interest, though possibly (from an economic point of view) not of much importance at present, since 'iron-mountains' existed in other parts of the world, in regions more accessible than this. Yet the abundance of iron occurring in these old crystalline rocks might, in part, account for the great spread of laterite noticed by Barrat and others in connection with the superficial deposits of the Congo Basin.

Dr. JOHN W. EVANS referred to the occurrence of similar hills of iron-ore in connection with the crystalline schists in British Central Africa and Southern India. He thought that the word laterite should be confined to the products of the alteration of alumina-bearing silicates, in the course of which the silica was wholly or partly removed. He also remarked on the interest of the occurrence, in the country dealt with in the paper, of the north-westerly and south-easterly strike which was so common in the Equatorial regions of the earth's surface.

Mr. Howe, in reply to Mr. Gibson, said that some of the rocks described undoubtedly bore a resemblance to certain gold-bearing rocks of South Africa; but no gold had been noticed in the area covered by the paper, although it had been discovered in the region somewhat to the south.

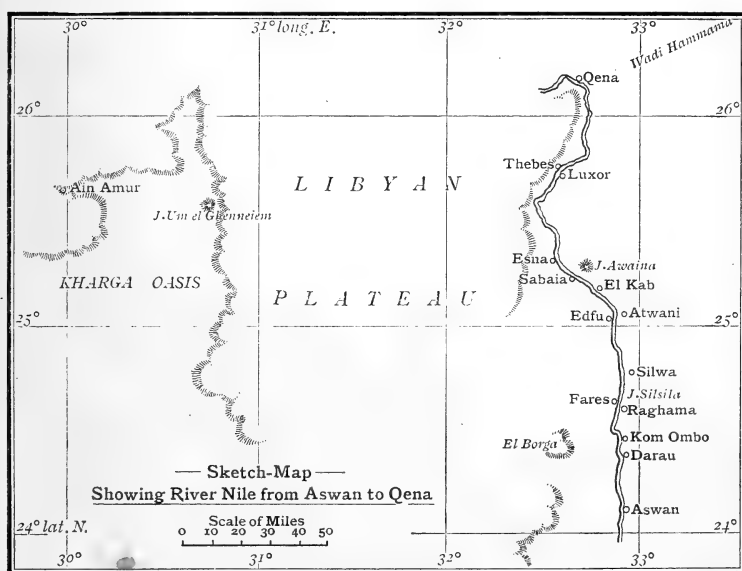
The results of M. Preumont's traverses brought forward no facts in favour of an extension of the so-called Karroo type of deposit in the Upper Uelle Basin; on the contrary, these rocks appeared to be absent over the whole area east of the granite-ridge which separates the Uelle from the Rubi. The specimen of chert from Suronga was obtained from loose blocks, therefore nothing certain could be deduced from that occurrence. The 'Karoo' line on Mr. Hudleston's map would still remain broken, so far as the evidence now presented was concerned.

With regard to the word laterite, it was not proposed to use that name for the conglomeratic deposits directly derived from the breaking-down of the iron-ore-beds of Mount Tena, Mount Gaima, Mount Angba, etc.: 'limonitic conglomerate' was the term used by M. Preumont in all cases. But there seemed to be no doubt that some of the laterite described by Cornet was correctly so named, and was represented, along with other forms, in that part of the Congo Basin.

31. *The Relations of the Eocene and Cretaceous Systems in the ESNA-ASWAN REACH of the NILE VALLEY.* By HUGH JOHN LLEWELLYN BEADNELL, F.G.S., late of the Egyptian Geological Survey. (Read June 21st, 1905.)

IN the autumn of 1904 I had occasional opportunities of examining the desert-margins on both sides of the Nile Valley, between Aswan and Esna. The geological information hitherto published on this part of Egypt<sup>1</sup> is so scanty that no apology is needed for putting on record the following observations, which, although disconnected, have an important bearing on a somewhat vexed question of Egyptian geology, namely, the mutual relations of the Cretaceous and Eocene systems.

Fig. 1.



[5 miles = approximately 8 kilometres.]

(1) The Kom-Ombo Plain.

From Aswan to Darau the valley is comparatively narrow. Immediately north of the latter place it opens out, from a narrow gorge closed in by sandstone-hills, to a broad plain bounded by an undulating sandstone-desert on the west side, and by the ordinary

<sup>1</sup> Schweinfurth's paper, 'Am westlichen Rande des Nilthals zwischen Farschüt & Kom Ombo' *Peterm. Mitth.* vol. xlvii (1901) pp. 1-10, records a number of valuable observations on the botany, geology, and archæology of this part of the Nile Valley.

sandstone-hills on the east: the latter running round in a wide curve, and not approaching the river until Jebel Silsila, 30 kilometres ( $18\frac{3}{4}$  miles) farther north, is reached. In the centre of this area, on the eastern bank of the river, is the temple of Kom Ombo, from which the plain takes its name.

As has long been recognized, the plain is superficially an extensive alluvial deposit; in addition to the sands and clays, with fluviatile shells and occasional mammalian bones, bands of tufaceous limestone are met with in the neighbourhood of Fatura. These deposits cannot be classed with the recent Nile alluvium, as they belong to the period of the great Pleistocene lakes of the Nile Valley, and have their surface some 25 metres (82 feet) above the high-flood level of the present day. The plain apparently slopes westward, and the deposits thin out in that direction, indicating that the material was probably derived mostly from the higher hill-ranges to the east, whence one or more feeder-streams entered the lake.

North of Kom Ombo the river curves, and undercuts the western desert, exposing a 20-metre (65-feet) section of very markedly-foliated and false-bedded argillaceous strata. The lowest beds visible are some 15 metres (49 or 50 feet) of finely-bedded clays, often sandy in character, with bands of sand-rock; they are overlain by hard and soft, ferruginous, false-bedded sandstones, passing upward, as noted by Schweinfurth,<sup>1</sup> into coarse grits and pebbly beds. The gravelly layers are made up of round and sub-angular quartz- and flint-pebbles, cemented in places into a conglomerate. The general dip is northward, and a short distance down stream the argillaceous beds are lost below river-level, the coarse sandstones and interbedded conglomerates forming the entire cliff. The last-named deposits may possibly be unconformable to the clays below, and belong to the Pleistocene lacustrine period; on the other hand, the whole of the beds exposed may be of Nubian-Sandstone age, but this can only be determined by more detailed examination.

Near the villages of Fares and Raghama, 20 kilometres ( $12\frac{1}{2}$  miles) down stream of Kom-Ombo temple, Danian beds occur at river-level. Schweinfurth (*loc. cit.*) was the first to note the unexpected occurrence of Upper Cretaceous and Lower Eocene limestones in this neighbourhood, although he was unable to ascertain to what particular part of the Upper Cretaceous succession the exposed beds should be assigned. About 4 kilometres ( $2\frac{1}{2}$  miles) south of Fares a conspicuous area of white limestone occurs close to the river-bank, its outcrop covering perhaps a square kilometre (.386 square mile). On the south side the plain consists of grey laminated clays, which are overlain by from 20 to 25 metres (65 to 80 feet) of fairly hard grey-and-white shaly marl and fissile chalky limestone, the whole series dipping northwards at an angle of about  $5^{\circ}$ . The uppermost bed is hard, grey, and siliceous. Fossils are scarce, but the presence of *Echinocorys vulgaris*, *Schizorhabdus libycus*, and *Ostrea aff. vesicularis* establishes the age of these beds as Upper Danian, and as the

<sup>1</sup> Peterm. Mitth. vol. xlvii (1901) p. 10.

equivalent of the White Chalk of the oases. The limestones appear to be conformable to the underlying clays, which may themselves form the continuation of the foliated argillaceous beds described above.

A little farther down stream, notably at Jebel Mayahi, near Raghama, on the right bank, the same marls and limestones (although here the echinids and sponges were not noticed) are only separated from highly-fossiliferous nummulitic and *Operculina*-Limestones, of Lower Eocene age, by an 8-metre ( $26\frac{1}{4}$ -feet) band of clays.<sup>1</sup> The Eocene limestone is much broken up, but the size and position of the blocks preclude the possibility of their having been transported. In all probability, they represent the remains of a once far more extensive bed, which has been broken up and lowered by the removal of the soft, easily-disintegrated clays below.<sup>2</sup> With the masses of displaced Eocene limestone are huge angular boulders, in a conglomerate of smaller fragments, largely mixed up with pulverized clays from below. When the Pleistocene lake stood at this level, the clays would have been easily removed, and the limestones let down and partly broken up by the action of currents and shore-waves.

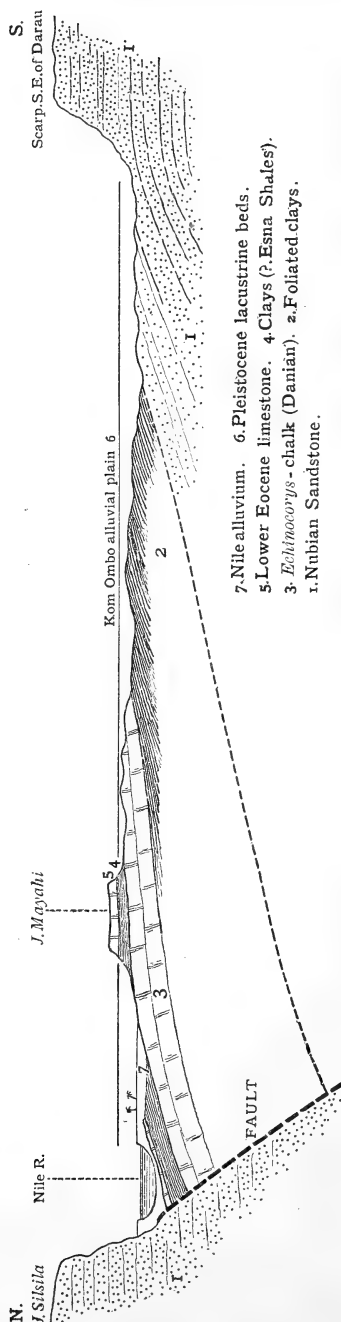
A short distance farther north, nearly opposite Fares, a ridge trending eastwards from the river-bank is covered with big blocks of Eocene limestone. The surfaces of the limestone show vermicular sand-etching, and are pierced by numerous holes; the latter seem to be cavities left by the weathering-out of fossils, rather than to be the work of boring mollusca, for which they might easily be mistaken. In this locality the intervening clays appear to have been entirely removed, the Eocene limestone lying almost directly upon a white, shaly marly limestone. No fossils were collected in the underlying rock, which, although closely resembling the *Echinocorys*-Beds farther south, may possibly belong to a somewhat higher horizon. It may be the equivalent of the limestone which immediately overlies the shales in the base of the cliffs at Thebes.

The occurrence in the Kom-Ombo region of the Danian *Echinocorys*-Chalk and of Eocene *Operculina*-nummulitic limestones at river-level, can only be explained on the supposition of faulting of some magnitude. Dr. Blanckenhorn (*loc. cit.*), without coming to any very definite conclusions, discusses the question as to whether the occurrence is to be explained by the (hypothetical) Eocene-Cretaceous unconformity, or whether it is the result of post-Eocene and pre-Pliocene disturbances.

At Jebel Silsila, a few miles to the north, the much older Nubian Sandstones form a range of hills rising to a considerably-higher level. In the hill of El Barga, 30 kilometres ( $18\frac{3}{4}$  miles) west of Kom Ombo, the Libyan Limestones overlying the Upper

<sup>1</sup> A list of the Eocene fossils occurring here is given by Dr. Max Blanckenhorn, 'Neues zur Geologie & Paläontologie Ägyptens: IV' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. liii (1901) p. 326.

<sup>2</sup> Dr. Blanckenhorn (*op. cit.* pp. 327-29) calls especial attention to the part which the disintegration of the soft Lower Eocene and Cretaceous clays has played in the formation of portions of the Nile Valley.

Fig. 2.—Generalized section from *Jebel Silsila to Darau*.

[The Nile is crossed at an acute angle by the line of section, the fault shown lying nearly at right angles to the Silsila river-gorge.]

Cretaceous beds are found at their proper level, 400 metres (1312 feet) above the sea. We must therefore assume a fault of some 300 metres (984 feet) downthrow, as high-flood level at Fares is only 90 metres (295 feet) above the sea. It is possible that this estimate may be excessive, as the difference in level of the limestones at river-level and identical beds in the scarp of El Borga may be partly due to the disintegration and removal of the argillaceous deposits. It seems probable, however, that faulting was the primary cause of the great plain of Kom Ombo, which may perhaps be regarded as a 'graben' of some magnitude, the Eocene and upper limestones and clays of the Cretaceous forming a floor surrounded by a range of Nubian - Sandstone hills. The accompanying figure is a generalized section across the region from Jebel Silsila to Darau.

## (2) Jebel Silsila.

The Kom - Ombo plain has two outlets through the bounding sandstone-range to the north; they are about a kilometre (= two-thirds of a mile) apart, and at the present day the river occupies the westernmost of the two, cutting through the hills known as Jebel Silsila. Schweinfurth described the river here as running through a narrow channel



(395 metres=1296 feet wide) of great depth, occupying the site of a fault or fissure in the sandstone.<sup>1</sup> He considered that there was certainly a cataract here at the time of the Kom-Ombo lake, although if the stated identity<sup>2</sup> of level of the lacustrine beds on either side be correct, the sandstone-block intervening between the two passes of the present day was probably an island in the midst of a long continuous lake. Nowadays the river washes the sandstone-escarpment on both banks for a distance of a kilometre (=two-thirds of a mile). The Nubian Sandstone of Jebel Silsila is mostly hard and massive, and it was here that much of the stone for the Egyptian temples was quarried. Bands of clay are almost absent, the sandstone in places having an unbroken thickness of over 20 metres (65 feet). Vertical rectangular jointing occurs in the rock, and evidently full advantage was taken of it in quarrying. The interior of the quarries is well protected, and in many instances the tool-marked faces remain astonishingly fresh. Irregular bands full of round, elongated, red ferruginous concretions impart to the rock a peculiar appearance in places.

Jebel Silsila is itself of no special geological interest, being due to an excessively-hard homogeneous development of sandstone, with almost entire absence of thick argillaceous bands.

### (3) Silwa to Edfu.

Here, for the first time, the unfossiliferous Nubian Sandstones and shales are capped by shelly limestones and bone-beds of Campanian age; these fossiliferous beds were first recorded by Figari Bey,<sup>3</sup> some forty years ago. The northerly dip is probably not much more than the general slope of the valley, and consequently the series is practically identical from Silwa to Edfu, though becoming less arenaceous in character as it is followed northwards. Within this region the very hard metre-thick ( $3\frac{1}{4}$  feet) sandstone-beds break up, leaving considerable areas of ground strewn with big blocks of irregular shape, the softer clays having been extensively denuded from below. The valleys running eastwards through this district are evidently cut out where soft shales have existed, the areas in which sandstones are thick and predominant being occupied by groups of hills and spurs abutting on the cultivated lands.

The section described on the following page was measured from the village of El Atwani, in the hills about one kilometre (=two-thirds of a mile) north-east of Edfu Railway-station. The mass of oyster-limestone on the top of the escarpment overlooking the cultivated area must be out of place, as the same bed in its true position was found farther inland, where the remainder of the section was measured.

<sup>1</sup> Peterm. Mitth. vol. xlvii (1901) p. 9.

<sup>2</sup> Sir William Willcocks, 'Egyptian Irrigation' 2nd ed. (London, 1899) p. 7.

<sup>3</sup> 'Studiî scientifici sull' Egitto & sue Adiacenze, compresa la Penisola dell' Arabia Petrea' Lucca, 1864-65.

## SECTION IN THE HILLS EAST OF EDFU RAILWAY-STATION. (In descending order.)

1. Hard oyster-limestone, very cherty in part. Oysters of *O. Forgemolli*, *O. Villei* types. (2 metres =  $6\frac{1}{2}$  feet.)
2. Thinly-bedded shaly sandstones. (10 metres = 33 feet.)
3. Hard ferruginous bone-and-coprolite bed, with ferruginous concretions. ( $\frac{1}{2}$  to 2 metres =  $1\frac{1}{2}$  to  $6\frac{1}{2}$  feet.)
4. Grey laminated clays; chelonian (?) remains. Hard sandy bed below. (12 metres =  $39\frac{1}{2}$  feet.)
5. Yellow-weathering, drab-coloured, flaggy, ripple-marked sandstone with shaly partings. Plant-remains.
6. Ironstained grey, green, and blackish saliferous clays, with ferruginous concretions and bands of shale and sandstone. Plant-remains.
7. Yellow-green clays, with a mottled concretionary band. At the base 6 metres (or  $19\frac{3}{4}$  feet) of laminated clays, with plant-impressions.
8. Hard brown (calcareous) sandstone, with occasional shell-casts.
9. Laminated ironstained grey clays, with plant-remains. (8 m. =  $26\frac{1}{4}$  feet.)
10. Ripple-marked flaggy sandstones with partings of softer sandy beds. Band of cone-in-cone near the top (30 cm., or about 1 foot). At the summit is a hard ferruginous band, giving rise to a subsidiary plateau.
11. Soft shaly sandstone, interleaved with sandy shales. Occasional ferruginous concretionary bands.
12. Flaggy, ripple-marked yellowish sandstones, with red ferruginous concretionary bands.
13. Greenish, often sandy, clays.

Base, cultivation-level.

Approximate total thickness: 114 metres = 374 feet.

The presence of well-developed cone-in-cone structure in one of the argillaceous beds is interesting, as this seems to be the first record of its occurrence in this country. In the hills farther back, about a kilometre north-west of the triangulation-beacon ( $5\frac{1}{4}$  kilom. =  $3\frac{1}{4}$  miles north-east of Edfu Railway-station), a hard bed of beautifully-developed cone-in-cone occurs, probably on the same horizon as that mentioned in the section. The oyster-limestone here is notable, on account of its hard siliceous character; usually it forms the summits of the higher hills, and is the youngest bed in the district.

Throughout this region the clays and shales contain varying quantities of nitrate of soda, and are largely worked by the peasants for use as fertilizers.

#### (4) El Kab and Mahamid.

One of the chief points of interest in this neighbourhood is the occurrence of springs in the beds of the wadis emerging at El Kab and Mahamid. The water is clear, but insipid and ferruginous to the taste. As the basal slopes of the hills forming the Mahamid wadi are so often encrusted with a saline deposit, I am inclined to believe that the water issues from the sandstones themselves, and is not derived from the Nile-Valley gravels.

Near Mahamid the summits of many of the hills and ridges are capped by a bed of rolled Eocene pebbles, showing that the Pleistocene high-level lake extended all over this region, though only where

there was drainage from higher land to the east were deposits of gravel brought down and laid out on the bed of the lake.<sup>1</sup> Prof. Hull, in discussing the level of the ancient Nile, refers to the terraces on the right bank at El Kab.<sup>2</sup>

### (5) Sabaia and Jebel Awaina.

The sides of the wadi emerging just east of Sabaia Station show 8 metres ( $26\frac{1}{4}$  feet) of finely-laminated light-grey clays, capped by a 2-metre ( $6\frac{1}{2}$ -feet) band of hard, white, fissile, marly, often siliceous limestone, with an intimately associated bone- (or rather coprolite-) bed and oyster-limestone. This bed, if not identical with, is practically on the same horizon as, the oyster-limestone capping the hills between Edfu and Silwa. From the intimate association of the oyster-limestone (containing oysters of the *Forgemolli*, *Villei*, etc. group) and bone-bed, and from their position between the almost unfossiliferous sandstones and shales below and the *Pecten*-Marls above (in Jebel Awaina), it is highly probable that this hard band is the equivalent of the *Ptychoceras*-Limestone of Wadi Hammama to the north-east of Qena, which Mr. Barron & Dr. Hume believed to form the upper limit of the Cretaceous, and described as being unconformably overlain by the *Pecten*-Marls, which they regarded as of Eocene age.<sup>3</sup> As I shall presently show, the oyster-limestone and associated bone-bed are conformable to the overlying clays and *Pecten*-Marls; the last-named occur low down in the Cretaceous, being overlain by a considerable thickness of Campanian and Danian clays and chalky limestones, which pass with perfect conformity into the basal beds of the Eocene above.

Jebel Awaina,  $8\frac{1}{2}$  kilometres ( $5\frac{1}{3}$  miles) north-east of Sabaia Station, is the southernmost outlier of the Eocene nummulitic-limestone plateau. The peak rises to a height of some 450 metres (1476 feet) above sea-level, forming a conspicuous landmark in a desert which is much broken up, owing to the extent and softness of the underlying clays. A little to the south lies the much lower plateau formed of the Nubian Sandstones and shales, capped by the oyster-limestone and associated bone-bed of Campanian age. In the foothills and on the slopes of Jebel Awaina the intermediate beds are exposed, and the first fact that impresses the observer is the absolute conformity of the succession throughout.

It will be remembered that, in their memoir dealing with the Eastern Desert, Mr. Barron & Dr. Hume announced<sup>4</sup> the presence

<sup>1</sup> Schweinfurth has, I think, referred to these deposits, although I cannot, at the moment, give the exact reference.

<sup>2</sup> 'Observations on the Geology of the Nile Valley, & on the Evidence of the Greater Volume of the River at a Former Period' Quart. Journ. Geol. Soc. vol. lli (1896) p. 314.

<sup>3</sup> 'Topography & Geology of the Eastern Desert of Egypt' Egypt. Geol. Surv. Report (Cairo, 1902) pp. 165-89.

<sup>4</sup> *Op. cit.* pp. 117, 176, & 184-86.

of a well-marked unconformity between the Cretaceous and Eocene systems. This was based partly on apparent differences of dip between the *Ptychoceras*-Limestone and the overlying *Pecten*-Marls, and partly on the occurrence of a bed of rolled pebbles of the *Ptychoceras*-Limestone in Wadi Hammama. Their field-evidence appeared to be confirmed by Mr. Bullen Newton's determination<sup>1</sup> of the *Pecten* from the marls as belonging to a new species of true Eocene facies, which he named *Pecten Mayer-Eymari*, though Dr. Blanckenhorn<sup>2</sup> maintained that the species was identical with Zittel's Campanian and Danian species, *P. farafrensis*. My colleagues, at the time, felt that the weight of field-evidence supported Mr. Newton's view, especially as the adoption of Dr. Blanckenhorn's determination appeared to involve them in an intra-Cretaceous unconformity.

Zittel's type of *Pecten farafrensis* had not at that time been figured, but in 1902 Dr. J. Wanner described and figured<sup>3</sup> the original type of the species, and Mr. Barron & Dr. Hume added<sup>4</sup> a note to their memoir (which had already been printed off) admitting the justification of Dr. Blanckenhorn's contention.

The succession which I observed at Jebel Awaina settles the question once and for all. The *Pecten*-Marls, far from forming the basal member of the Eocene, occur low down in the Cretaceous, near the base, in fact, of a 100-metre (328 feet) thickness of clays (the equivalent of the 'ashen-grey clays' of the oases) underlying the *Echinocorys*-Chalk. Moreover, there is no unconformity between them and the *Ptychoceras*-Limestone below, from which they are separated by a 30-metre (100-feet) band of laminated clays, the occasional slight differences of dip being due to faults and minor local disturbances.

In the short time at my disposal at Jebel Awaina I was unable to do more than note the principal points in the succession. These, with the approximate thicknesses, are detailed below, in descending order.

#### EOCENE.

- LOWER LIBYAN.—1. Hard limestone with chert-concretions, in part crowded with *Nummulites*, *Operculina*, and shells of typical Eocene species ..... 20 metres = 66 feet.
- ESNA SHALES.—2. Laminated, green and grey, shaly clays, largely obscured by débris, forming a perfectly-conformable passage between Cretaceous and Eocene ..... 60 metres = 197 feet.

<sup>1</sup> 'Notes on some Lower Tertiary Shells from Egypt' Geol. Mag. 1898, pp. 535-36.

<sup>2</sup> 'Neues zur Geologie & Paläontologie Ägyptens: II—Das Paläogen' Zeitschr. d. Deutsch. Geol. Gesellsch. vol. lii (1900) pp. 411-12.

<sup>3</sup> 'Die Fauna der obersten weissen Kreide der Libyschen Wüste' Paläontographica, vol. xxx, pt. ii (1902) pp. 114-15 & pl. xvii, figs. 1-4.

<sup>4</sup> 'Topography & Geology of the Eastern Desert of Egypt' Egypt. Geol. Surv. Report (Cairo, 1902) footnote, p. xi.

## UPPER CRETACEOUS.

DANIAN.—3. White, brown-weathering (sometimes pink), fissile, shaly marly limestone and chalk, with veins of celestine. *Ostrea* aff. *vesicularis*. This bed will probably be found to be identical with the *Echinocorys*-Chalk.

20 metres = 66 feet.

4. Green and blue, laminated, shaly clays, with a white marly limestone-band near the centre containing *Ostrea vesicularis*, *Rhynchonella* sp. nov.<sup>1</sup>, and *Baculites*. The equivalent of the 'ashen-grey clays' of the Southern Oases.

100 metres = 328 feet.

5. *Pecten*-Marls. White marly limestone, passing up into grey marls and marly clays with red ferruginous bands, crowded in places with *Pecten farafrensis*, fish-remains, and shell-casts ..... 8 metres = 26 feet.

6. Laminated grey and ironstained shales.

30 metres = 98 feet.

Beds 5 & 6 correspond to the '*Exogyra*-Series' of the Southern Oases.

CAMPANIAN.—7. Hard oyster-limestone, with intimately-associated bone-and-coprolite bed. Oysters of *Ostrea-Forgemolli*, *O.-larva*, and *O.-Villei* types. Hard, fissile, splintery, siliceous limestone at the base ..... 4 metres = 13 feet. This bed corresponds to the *Ptychoceras*-Limestone of Wadi Hammama, etc., and the hard limestone capping the bone-bed series in the Dakhla Oasis.<sup>2</sup>

8. Sandy clays, shales, and sandstones.

45 metres = 148 feet.

(Upper beds of the Nubian Series.)

With regard to the Esna Shales, in the foregoing section I have classified them as passage-beds. There is no doubt that they bridge over the period which elapsed between the deposition of the Cretaceous white chalk and the incoming of the Nummulitic sea. In some places, as at Thebes, the Esna-Shale fauna appears to have a considerable affinity with that of the 'ashen-grey clay-series'; in others, for instance Farafra Oasis, the presence of bands containing *Operculina*, etc. links them to the Eocene. Far more detailed work than has yet been carried out is necessary, before the age of this variable series in the different areas can be satisfactorily established, and consequently, for the present, it is preferable to refer to them as passage-beds.

## (6) General Conclusions.

At the Paris International Geological Congress of 1900, I brought forward<sup>3</sup> evidence from the Baharia Oasis and Abu Roash to show that there was a marked unconformity between the Cretaceous and Eocene systems in the northern part of

<sup>1</sup> This is the first record of the occurrence of the genus *Rhynchonella* in Egypt.

<sup>2</sup> H. J. L. Beadnell, 'Dakhla Oasis' Egypt. Geol. Surv. Report (Cairo, 1901) pp. 82, 83, etc.

<sup>3</sup> 'Découvertes géologiques récentes dans la Vallée du Nil et le Désert Libyen' Compte-rendu du viii<sup>me</sup> Congr. géol. internat. 1900 (Paris, 1901) pp. 839-53.

the country. This view is, I venture to think, founded on unassailable facts.

In the Farafra Oasis the actual junction of the Cretaceous clays with the Eocene Esna Shales was not identified, and, although I then suspected the existence of an unconformity as in Baharia, the observations that I have since made in Kharga Oasis and Jebel Awaina incline me to believe that the Farafra succession falls into line with that which obtains in the southern part of the country.

The Jebel-Awaina succession shows that, in the southern part of the country, where the Upper Cretaceous and Lower Eocene occur in their fullest development, there is, in Zittel's words,<sup>1</sup>

'no sharp line of demarcation between the Cretaceous and Tertiary, and no disturbances in the stratigraphical succession.'

Zittel having based his conclusions specially on observations in the oasis of Kharga, I was particularly anxious to examine for myself the succession in that depression; especially as Dr. J. Ball,<sup>2</sup> biased perhaps by Messrs. Barron & Hume's results in the Eastern Desert, in 1900 announced the presence of an unconformity between the Cretaceous and Eocene in that oasis.

Dr. Ball's conclusions were mainly based on the supposed irregular variation of the Esna Shales; but, where this occurs, it is mainly due to the fact that, with a slight increase of carbonate of lime, these beds become almost indistinguishable from the overlying marls and marly limestones of the Eocene. Moreover, in Jebel Um-el-Ghenneiem, where Dr. Ball estimated their thickness at only 15 metres (49 feet), I found some 55 metres (180 feet) of green clays between the *Echinocorys*-Chalk and the Eocene marls and limestones, and a perfectly-conformable succession throughout.

Near Ain Amur there is a considerable development of fossiliferous limestones at the summit of the Cretaceous, and many of the fossils are hardly distinguishable from Eocene species.

With this bald statement of some scattered observations of the last few months I must now be content, and reserve details of the Ain-Amur and other sections for future publication. If I have brought forward sufficient evidence to show that the case for an unconformity between the Eocene and Cretaceous in the southern part of the country is not proven, my object is accomplished. The detailed survey of the Esna-Aswan reach of the Nile Valley, now being carried out by my colleague Dr. W. F. Hume,<sup>3</sup> will doubtless throw full light on points which are still obscure.

<sup>1</sup> 'Beiträge zur Geologie & Paläontologie der Libyschen Wüste: I' Paläontographica, vol. xxx, pt. i (1883) p. 90.

<sup>2</sup> 'Kharga Oasis' Egypt. Geol. Surv. Report (Cairo, 1900) p. 94.

<sup>3</sup> Dr. Hume asks me to state that he has just found a rich fauna, identical with that characterizing the 'ashen-grey clays' of the oases, in the clays above the *Pecten*-Marls in the neighbourhood of Esna (eastern bank). The fossils, as in the Western Desert, are preserved in limonite. This discovery fully confirms my conclusions as to the age of Bed No. 4 in the Jebel-Awaina succession.—April, 1905.

## DISCUSSION.

Capt. H. G. LYONS remarked on the interesting character of the area described by the Author, situated as it was at the end of the Nile-Valley faults. The more recent deposits referred to would probably, when worked out in detail, throw valuable light on many points connected with the history of the valley. The evidence of a conformity between the Cretaceous and the Eocene strata was most interesting, and would certainly necessitate some modification of the views hitherto held concerning the area lying to the north. Until further detailed examination had been made, he would prefer to suspend judgment on the point, whether this conformity continued as far as the Farafra Oasis, since in the Baharia Oasis, not 70 miles farther north, the unconformity was most strongly marked.

Mr. R. BULLEN NEWTON wished to state his position with regard to the shell figured and described by himself in 1898, as *Pecten Mayer-Eymari*, which had been alluded to by the Author. This Egyptian shell was obtained from Eastern Desert and Nile-Valley localities, being regarded by Messrs. Barron & Hume as of Lower Eocene age. As its facies seemed to support this horizon, it was so described. In 1900 Dr. Blanckenhorn, in his memoir on the Eocene of Egypt, noted the fact that *Pecten Mayer-Eymari* was synonymous with *P. farafrensis* of Zittel (1883), and belonged to Upper Cretaceous rocks. At this date Zittel's shell was known only as a list-name, never having been figured or described; and it was not until 1902 that Dr. Wanner published its details, and followed Dr. Blanckenhorn in placing *P. Mayer-Eymari* in its synonymy. A subsequent study of examples of the so-called *P. farafrensis* from the Libyan-Desert areas of Farafra and Baharia had convinced the speaker that, allowing for a somewhat variable shell, the two forms may be included under the same specific name, which, on account of priority, must now be known as *P. Mayer-Eymari*, the old name suggested by Zittel not being retainable. A further palæontological investigation of the fauna associated with this shell confirmed in every way Dr. Blanckenhorn's statement that it belongs to Upper Cretaceous rocks and ranges from the Campanian to the Danian: the Campanian forms being restricted to the Eastern Desert and Nile-Valley localities, while the Danian are confined to the Libyan Desert. Moreover, the Author had eliminated the theory of an unconformity existing between these *Pecten Mayer-Eymari* Beds and the rocks beneath, and so fully supported the view as to the Cretaceous age of these deposits.

The PRESIDENT said that he was glad to find that the Director of the Geological Survey of Egypt agreed with the main conclusions of the Author. With reference to an unconformity occurring at no great distance from an area where the beds were conformable, he thought that at least three such cases could be cited in the limited area of Great Britain.

The AUTHOR, in reply, observed that the President's allusion to similar cases of rapid change from conformity to unconformity

had already met the point raised by Capt. Lyons. Unfortunately, for want of exposures in the intervening areas, it was almost impossible to follow the change from point to point. Mr. Bullen Newton had fully explained the reasons which led to the error in the determination of the *Pectens* in question. The field-notes accompanying the specimens seemed conclusive evidence that the latter were of Eocene, and not of Cretaceous, age. Moreover, as he (the Author) had already mentioned, in some localities (notably near Ain Amur) the passage from Cretaceous to Eocene was so gradual that near the junction, fossils, typically characteristic of Cretaceous beds in other places, occurred side by side with forms having distinct Eocene affinities.



32. *A CONTRIBUTION to the STUDY of the GLACIAL (DWYKA) CONGLOMERATE in the TRANSVAAL.*<sup>1</sup> By EDWARD T. MELLOR, B.Sc., F.G.S. (Read June 21st, 1905.)

WITH the exception of the gold-bearing conglomerates of the Witwatersrand, the Glacial or Dwyka Conglomerate at the base of the Karroo System has probably attracted more attention from geologists than any other rock occurring in South Africa. While, however, the rocks of the Rand derive their importance mainly from their economic value, the interest manifested in the Glacial Conglomerate over a period of fifty years<sup>2</sup> has depended entirely upon purely-geological considerations. The diversity of views which so long prevailed, as to the origin of the Dwyka Conglomerate, was no doubt largely due to the fact that these views were in many cases necessarily based upon the examination of hand-specimens. The study of the rock in the field, however, can hardly be said to have resulted in any marked unanimity of opinion among local geologists, the majority of whom favoured an igneous origin for the rock in question; and, although the glacial view was stated by P. C. Sutherland<sup>3</sup> as far back as 1868, and later supported by G. W. Stow,<sup>4</sup> Mr. E. J. Dunn,<sup>5</sup> and Dr. A. Schenck,<sup>6</sup> it is only quite recently that the accumulation of evidence in favour of the glacial origin of the rock can be said to have led to a general acceptance of this view.

To South African geologists the Glacial Conglomerate affords the only common geological horizon as yet available for the various colonies, while its similarity to corresponding formations in India, Australia, and South America gives a wider interest to the investigation of the conditions under which the vast glacial deposits of South Africa were laid down.

### Recent Studies of the Glacial Conglomerate.

A description of the Dwyka Conglomerate, as developed in the Vryheid district, now forming the northern portion of Natal, was given by Dr. G. A. F. Molengraaff in 1898.<sup>7</sup> In the following year,

<sup>1</sup> Communicated by permission of the Director of the Geological Survey of the Transvaal.

<sup>2</sup> For references to the literature of the subject, see G. S. Corstorphine, *Ann. Rep. Geol. Comm. Cape of Good Hope for 1899 (1900)* pp. 4-17.

<sup>3</sup> 'On the Geology of Natal' Pietermaritzburg, 1868.

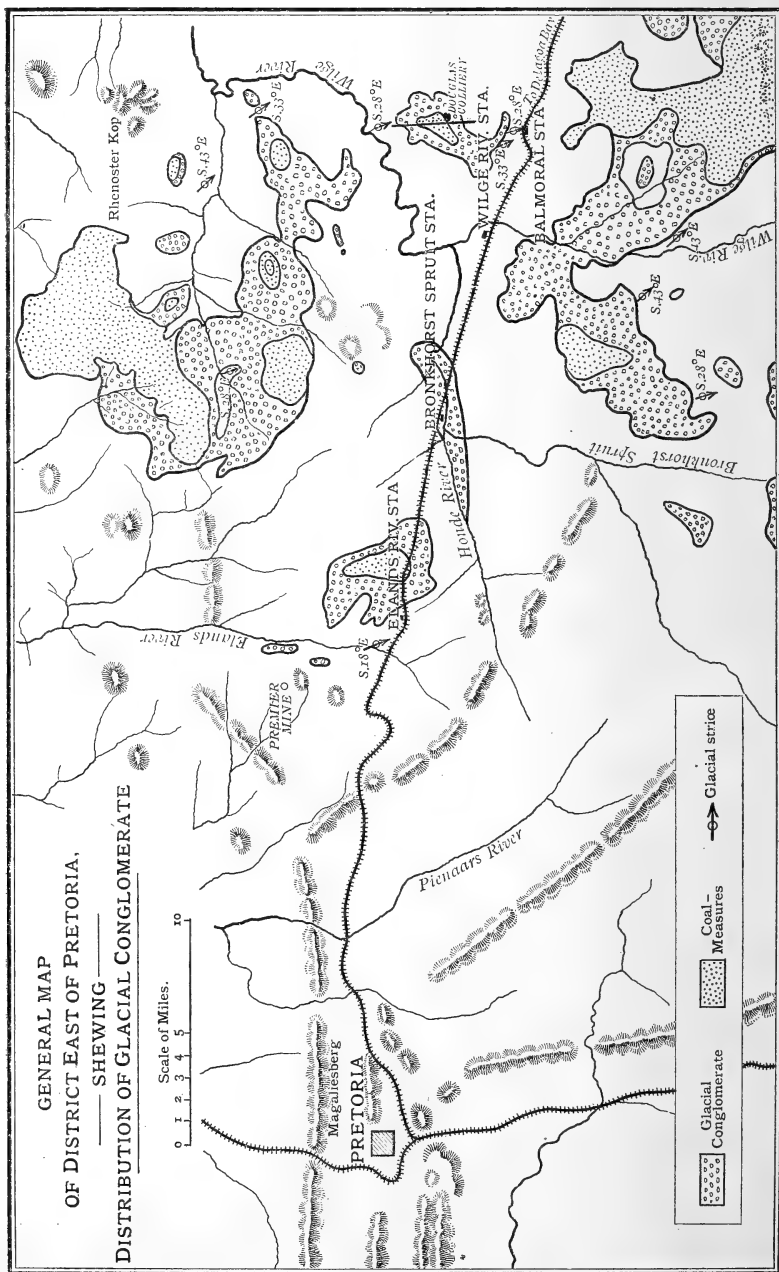
<sup>4</sup> 'On some Points in South-African Geology' *Quart. Journ. Geol. Soc.* vol. xxvii (1871) pp. 497-548.

<sup>5</sup> 'Geological Sketch-Map of South Africa' London, 1875.

<sup>6</sup> 'Die Geologische Entwicklung Südafrikas' *Peterm. Mitth.* vol. xxxiv (1888) p. 225.

<sup>7</sup> 'The Glacial Origin of the Dwyka Conglomerate' *Trans. Geol. Soc. S. A.* vol. iv (1898) p. 103.

Fig. 1.



Messrs. A. W. Rogers & E. H. L. Schwarz studied the Conglomerate in the Prieska district of Cape Colony,<sup>1</sup> while in his report for the same year<sup>2</sup> Dr. Corstorphine compared the results there obtained with those of observers in other parts of South Africa, and emphasized the differences existing between the conglomerates, as developed in the southern parts of Cape Colony representing sub-aqueous deposits, and the more northerly phases representing true ground-moraines; a difference in mode of origin which accounts in part for the difference in the lithological characters between the northern and southern phases of the Conglomerate. This distinction has probably been further emphasized by the effect of the much greater thickness of strata, to the pressure of which the southern deposits were subjected, and also by the earth-movements in which the latter have been involved. The term 'Glacial Conglomerate' was applied by Mr. E. J. Dunn in 1873<sup>3</sup> to the outcrops in the northern portion of Cape Colony, Wylie's old name 'Trap-Conglomerate' being retained for those in the south. Two years later, Mr. Dunn<sup>4</sup> termed the southern outcrops, as typically developed near the Dwyka River, 'Dwyka Conglomerate,' still keeping the name 'Glacial Conglomerate' for the northern occurrences, a name which I have preferred to use in this and other descriptions of the Conglomerate in the Transvaal.

Although the Glacial Conglomerate occurs extensively in the Transvaal, being generally present at the base of the Karroo System, which occupies the greater part of the south-eastern portion of the Colony, it rarely affords good exposures or sections; and, perhaps, on this account it has not hitherto received much attention from geologists. The survey of a district lying eastwards from Pretoria, and extending from the neighbourhood of the diamond-fields to near Middelburg, has recently afforded much additional information with regard to the local character and disposition of the Glacial Conglomerate in this part of South Africa. The object of the present paper is to give some account of the results thus obtained.

### The Glacial Conglomerate in the Transvaal.

The situation and extent of the district which is dealt with more particularly here will be best seen by reference to the sketch-map on p. 680 (fig. 1). It lies on the northern edge of the principal area occupied by the Karroo System in South Africa, and includes a number of outliers separated by the progress of denudation from the main body of the formation. These outlying portions frequently include both the Glacial Conglomerate and the overlying shales, sandstones, and grits associated with coal-seams, which form the upper portion of the Karroo System in the Transvaal.

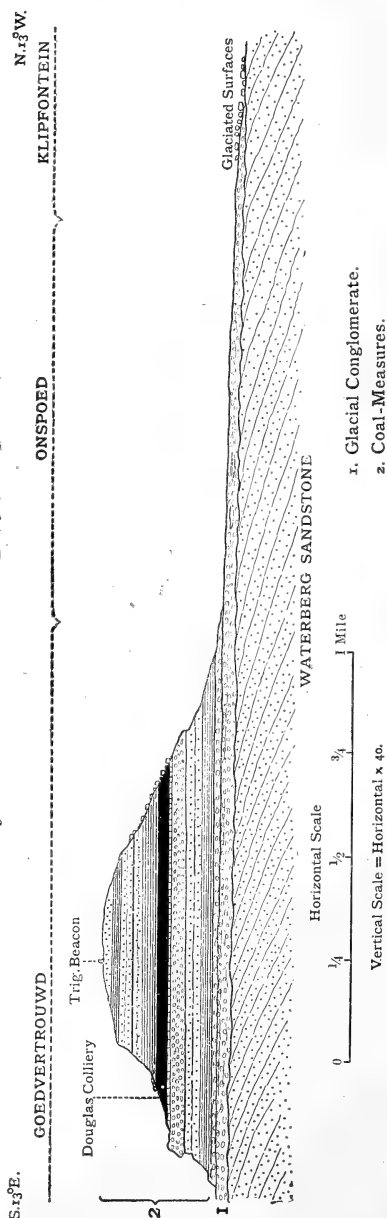
<sup>1</sup> Ann. Rep. Geol. Comm. Cape of Good Hope for 1899 (1900) pp. 65, 86 *et seqq.*

<sup>2</sup> *Ibid.* pp. 17 *et seqq.* & pp. 25 *et seqq.*

<sup>3</sup> 'Geological Sketch-Map of Cape Colony' London, 1873.

<sup>4</sup> 'Geological Sketch-Map of South Africa' London, 1875.

Fig. 2.—Section through the Glacial Conglomerates and coal-bearing strata, north of Balmoral (Transvaal), along the line shown in the map (fig. 1, p. 680).



[Reproduced, by permission, from Pl. XIX, fig. 2, Ann. Rep. Transvaal Geol. Surv. for 1903.]

consisting only of the Glacial Conglomerate or its weathered-out remnants, which frequently give good opportunities for study; while the intervening areas of older rocks afford information as to the source of much of the material incorporated in the Glacial Conglomerate, and having been denuded comparatively recently of their covering of Karroo rocks, they preserve approximately the character and outline of the land-surface upon which the glacial deposits were laid down. Round the margins of the Karroo outliers this old land - surface, dating back as far as Carboniferous time, still preserves astonishingly-clear traces of ice-action.

From the southern and eastern margins of the main area occupied by Karroo rocks in South Africa towards its northern and western edges in the Transvaal, the Karroo System shows a considerable diminution in thickness; and, while in Cape Colony it attains a thickness of several thousands of feet, in

the Central and Northern Transvaal the entire formation probably

averages not more than 400 or 500 feet, and it is not possible at present to recognize in these portions of the Transvaal the many divisions which the Karroo System presents in its fuller development in Cape Colony and Natal.

So far as our present knowledge goes, the Karroo rocks in the Central and Northern Transvaal may be divided into an Upper Division, consisting of sedimentary rocks including conglomerates, grits, sandstones, and shales, associated with coal-seams, referred to by Dr. Molengraaff as the 'High-Veld Series'; and a Lower Division, consisting of glacial deposits including the Glacial Conglomerate (Dwyka) and the associated shales and sandstones. The general succession of the beds and their relationship to the underlying formations in most localities is usually similar to that shown in the section (fig. 2, p. 682). In the district here referred to, the Glacial Conglomerate varies considerably in thickness, averaging about 50 feet. In places, where it has been deposited in depressions in the old land-surfaces, it may attain a thickness of 200 feet or more; while, on the other hand, it may be locally absent altogether, the Upper Karroo rocks then resting directly upon the older formations.

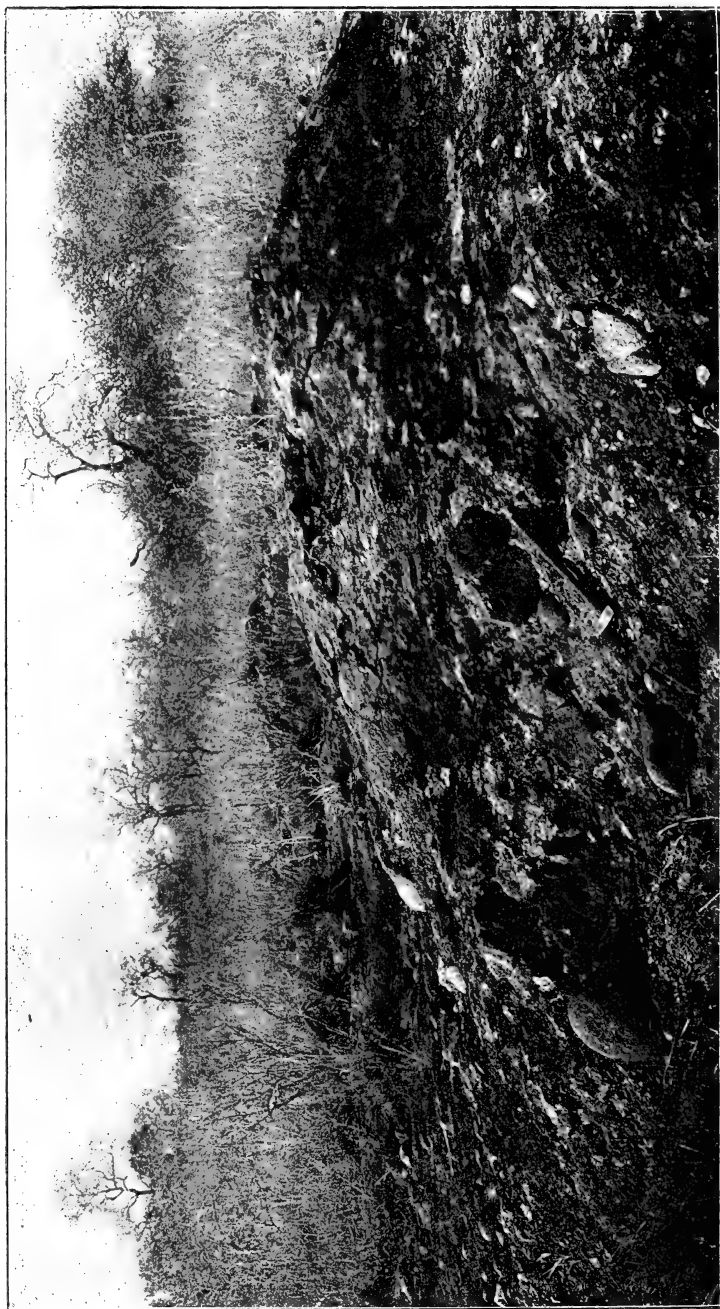
The following description of the Conglomerate is based upon that previously given by me in the Annual Report of the Geological Survey of the Transvaal for 1903.

When exposed at the surface, the Glacial Conglomerate is light-yellow in colour, while specimens from shafts and boreholes are frequently greenish or grey. Owing to the rapid disintegration of the rock at the surface into abundant sandy material, outcrops are rarely met with. When they occur, they have very generally the hummocky appearance shown in fig. 3 (p. 684), which represents a very characteristic example.

The matrix of the conglomerate is a sandy-looking material, consisting for the most part of sharply-angular fragments and grains of quartz, and of various rocks similar to those of which the boulders in the conglomerate are composed, including quartzites, hard shales, felsites, and granophyres occurring in the district. The fragments range in size from minute grains to pieces several inches in diameter. The proportion of quartzose material is usually great, and the rock weathers to sandy débris; but in some cases felspathic material is abundant, and the weathering of the matrix produces a whitish sandy clay.

Scattered through the matrix occur abundant boulders and subangular rock-fragments. These show no definite arrangement or orientation, large and small fragments lying confusedly together. The boulders and fragments measure generally from 1 to 3 feet in diameter, but may attain as much as 8 or 10 feet; they are usually faceted, and especially when composed of material not excessively hard and somewhat fine in grain, such as hard shales and weathered felsitic rocks, frequently show striations. The smaller pebbles are often traversed by a network of cracks, dividing them into a number of pieces which have been re-cemented into a whole.

Fig. 3.—Glacial Conglomerate at Toits Kraal, near the junction of the Elands and Olifants Rivers (Transvaal).



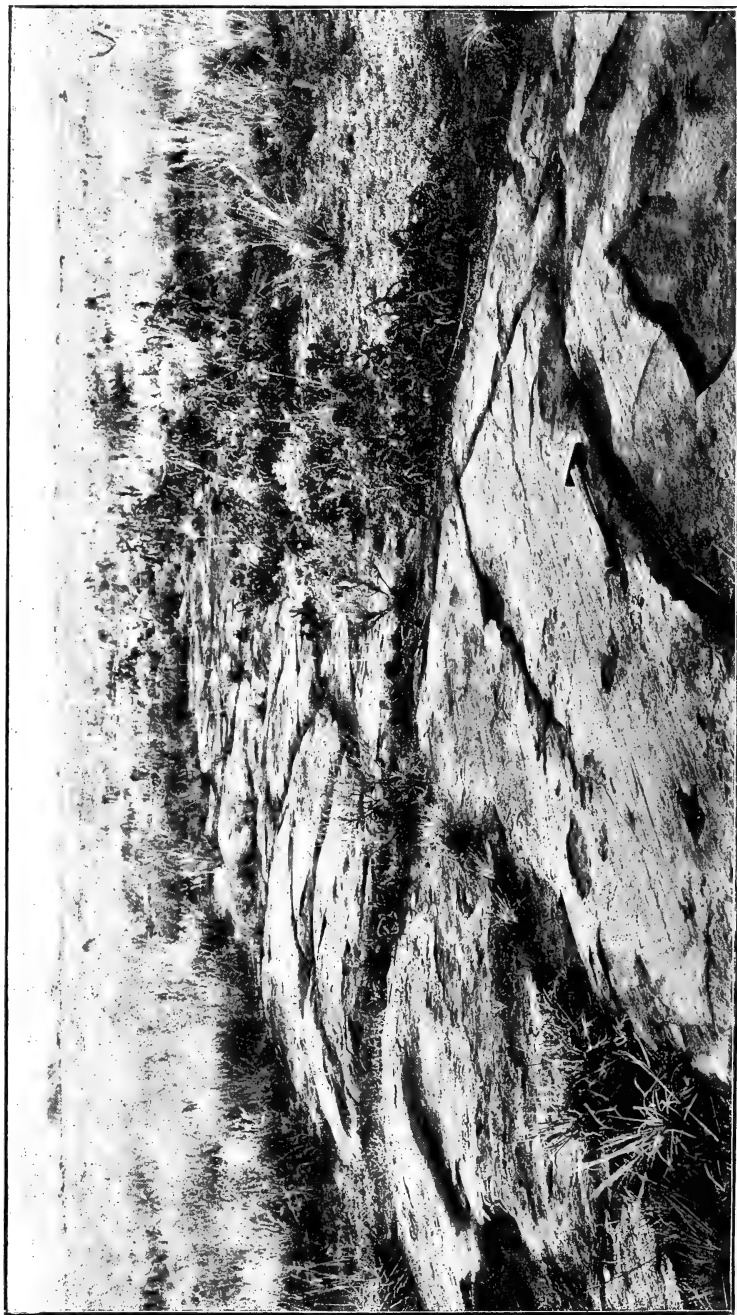
A group of boulders recently observed in the south-western corner of the farm known as Bosseman's Kraal, near the Wilge River, and south of the Eastern Railway-line, included the following members:—One boulder of white Megaliesberg Quartzite, 8 feet in diameter; one of Waterberg Conglomerate, 5 feet; three of Waterberg Sandstone, each measuring about 2 feet; two of coarse red granite, measuring respectively 8 and  $2\frac{1}{2}$  feet; and one of red-banded felsite, identical with the felsites of Rhenoster Kop, measuring 18 inches.

The greater number of boulders in the Conglomerate consist of rocks of local origin, which either immediately underlie any particular portion of the Conglomerate or occur to the northward of it. In the area shown in the map (fig. 1, p. 680), the great majority of the boulders consist of hard red quartzites and conglomerates from the Waterberg Formation and of the Red Granite, both of which occupy large areas to the north of the Eastern Railway-line. South of the ridge which is formed by the eastward extension of the Megaliesberg Quartzite, this rock has furnished many boulders to the Glacial Conglomerate; while, farther south again, on the Eastern Rand, many boulders are found, derived from the hard quartzites and 'bankets' of the Witwatersrand Series, together with abundant boulders of chert from the Dolomite to the north.

True bedding-planes are rarely seen in the Glacial Conglomerate, and then appear to be quite local. Certain zones are, however, richer in boulders than others, and the rock is frequently traversed by 'partings' which divide it into rude sheets, usually lenticular, with irregularly-undulating surfaces.

With the upper portions of the Conglomerate are sometimes locally associated beds of massive sandstone, and lenticular patches of white and cream-coloured shales and mudstones, which appear to have been deposited in 'pockets' in the Conglomerate and to consist of the finest glacial mud. In a section exposed on the banks of the Bronkhorst Spruit, immediately south of the railway-line, a thickness of 6 feet of these fine white shales and mudstones occurs, consisting of a succession of extremely-regular laminæ varying from a tenth of an inch to an inch and a half in thickness. The laminæ are readily separated one from the other. Their surfaces are either perfectly smooth, and similar in appearance and colour to that of a lithographic stone, or are covered with very delicate ripple-markings, of which as many as forty may occur in the space of an inch. Other markings occur which appear to be due to trains of eddies, such as might be produced in a film of water moving over fine glacial mud, by bigger particles lying on the smooth and gently-sloping surface. I have not hitherto found anything in the nature of fossils among these finely-laminated mudstones, although they would be admirably adapted for the preservation of vegetable-remains, such as frequently occur in the shales and sandstones which succeed the glacial beds.

Fig. 4.—Glaciated surface at Klipfontein, 6 miles north-north-west of Balmoral (Transvaal).





Evidence is plentiful that the Glacial Conglomerate was originally formed on a land-surface possessing considerable variety of feature. The denudation of the Conglomerate frequently exposes ancient escarpments of Waterberg Sandstone, the uppermost beds of which are often glaciated, while the Conglomerate on their southern slopes is as a rule especially rich in very big boulders. In other cases the Conglomerate fills old valleys, which are now in process of re-excavation, such as the valleys of the Wilge River and Bronkhorst Spruit.

The Waterberg-Sandstone Formation, which consists of a succession of conglomerates and sandy strata of extremely-various degrees of hardness—from soft sandstones to very resistant quartzites—almost invariably gives rise to landscapes of considerable diversity, including some of the most rugged and picturesque scenery in the Transvaal. In the district shown in the map (fig. 1, p. 680) between the Elands and the Wilge Rivers, however, where the removal of the overlying Karroo glacial deposits is still in progress, the Waterberg ridges continue to retain outlines characteristic of glaciated areas.

In the district here dealt with, the Glacial Conglomerate occurs at all levels within a range of about 350 feet, its lower limit varying with the contours of the underlying surface of older rocks. Its upper limit, marked by its junction with the horizontal beds of the Upper Karroo or High-Veld Series, occurs very regularly at an altitude of about 4900 feet above sea-level.

### Glaciated Rock-Surfaces.

The surfaces of the older rocks underlying the Glacial Conglomerate frequently present very clear evidence of glacial action.<sup>1</sup> The outcrops of the hard quartzites of the Waterberg Formation or the Pretoria Series, which formed part of the land-surface upon which the Glacial Conglomerate was laid down, are frequently rounded-off, polished, and sometimes very clearly striated. The constant alternations of heat and cold to which all rocks are subjected in the South African climate leads to the rapid destruction of brittle rocks, such as quartzites. Consequently the glaciated surfaces are broken up on exposure, and are only found on the immediate margin of the patches of Glacial Conglomerate, where the underlying rocks have been exposed comparatively recently. A typical example of these glaciated surfaces is shown in fig. 4 (p. 686). Such glaciated surfaces have been found distributed over an area of some 300 square miles, as shown in the accompanying map (fig. 1, p. 680). It will be seen from the compass-readings tabulated on the following page, that the striæ exhibit a remarkable constancy of direction.

<sup>1</sup> E. T. Mellor, 'On some Glaciated Land-Surfaces occurring in the District between Pretoria & Balmoral' *Trans. Geol. Soc. S. A.* vol. vii (1904) p. 18.

DIRECTION OF GLACIAL STRIÆ IN PORTIONS OF THE PRETORIA AND  
MIDDELBURG DISTRICTS (TRANSVAAL).

	<i>Farm.</i>	<i>Locality.</i>	<i>Direction</i> ( <i>true bearing</i> ).
1.	Rooikopjes, 209.	25 miles W. of Balmoral Station.	S. 18° E.
2.	Eenzamheid, 121.	2 m. N.W.	S. 28° E.
3.	Spitzkop, 407.	3 m. N.W.	S. 33° E.
4.	Klipfontein, 346.	6½ m. N.N.W.	S. 28° E.
5.	Schoongezicht, 316.	18 m. N.W.	S. 28° E.
6.	Elandsfontein, 245.	12½ m. N.	S. 33° E.
7.	Vlakfontein, 570.	15 m. N.N.W.	S. 43° E.
8.	Witpoort, 408.	9 m. S.W.	S. 43° E.
9.	Bosseman's Kraal, 531.	10½ m. S.W.	S. 43° E.
10.	Zorgvliet, 254.	16 m. S.W.	S. 28° E.

In nearly all cases, the glaciated surfaces afford clear evidence that the direction of the ice-movement was from the north southwards; and their evidence is further confirmed by the composition and distribution of the boulders in the Glacial Conglomerate, a very striking feature being the predominance in any locality of boulders formed of rocks occurring most abundantly (or probably, in some cases, exclusively) to the northward of their present position.

The constancy of direction shown by the glacial striations over wide areas, and the extensive development of the glacial deposits, point to the conclusion that in early Karroo times an ice-sheet of considerable magnitude existed as far north, at least, as the present position of the Northern Transvaal.

In the Prieska district of Cape Colony, Messrs. A. W. Rogers & E. H. L. Schwarz found the general trend of ice-movement to have been from north-north-east to south-south-west.<sup>1</sup> The same direction is given by Dr. A. Schenck from a locality near the junction of the Orange and Vaal Rivers<sup>2</sup>; in the Vryheid district Dr. G. A. F. Molengraaff gives the direction of movement as from north-west to south-east<sup>3</sup>; and in the examples cited above the general direction is from north-north-west to south-south-east. The direction of movement of the early Karroo ice-sheet in South Africa appears, therefore, to have been generally in a southerly direction, and its origin must be looked for to the north.

## The Northward Extension of the Glacial Conglomerate.

During the field-work of 1904, outliers of the Karroo System, including the Glacial Conglomerate, were found considerably farther

<sup>1</sup> 'The Orange-River Ground-Moraine' Trans. S. A. Phil. Soc. vol. xi (1900) p. 117.

<sup>2</sup> 'Ueber Glacialerscheinungen in Süd-Afrika' Verhandl. des VIIIten Deutsch. Geographentages in Berlin, 1889, p. 153.

'Geology of the Transvaal' Johannesburg, 1904, p. 69, note.

north than any previously met with.<sup>1</sup> These occur in the neighbourhood of the junction of the Elands and Olifants Rivers, about 90 miles north of the latitude of Johannesburg.

In this locality, the Glacial Conglomerate rests directly upon the Red Granite, and varies in thickness from 30 feet downwards. It is usually succeeded by about 3 feet of pale-grey shaly mudstones, followed by a variable thickness of well-bedded horizontal sandstones and coarse grits, which, however, probably nowhere exceed 50 feet. These sandstones and grits are exactly similar to those associated with the coal-seams of the High-Veld Series in the district farther south. The Karroo Beds appear to have been here deposited along an old valley in the Red Granite, corresponding nearly with the present course of the Elands River. A few miles farther north, patches of Karroo sandstones occur, without any underlying Conglomerate.

The coal-bearing rocks of Rhodesia appear to resemble the High-Veld Series of the Transvaal, although no mention has as yet been made of the occurrence in the former region of anything corresponding to the Glacial Conglomerate. It appears, however, probable that such a Conglomerate will be found, in some cases at least, to underlie the rocks associated with the coal-seams in that portion of South Africa.

#### DISCUSSION.

The PRESIDENT said that anyone who felt doubtful as to the glacial origin of the phenomena described, should examine the beautiful photographs exhibited by the Author. The glaciation was indisputable, but the explanation was not forthcoming, and became more and more difficult as these deposits were traced farther north.

<sup>1</sup> E. T. Mellor, 'Outliers of the Karroo System near the Junction of the Elands & Olifants Rivers in the Transvaal' *Trans. Geol. Soc. S. A.* vol. vii (1904) p. 133.

33. *The MICROSCOPIC STRUCTURE of MINERALS FORMING SERPENTINE, and their RELATION to its HISTORY.* By Prof. T. G. BONNEY, Sc.D., LL.D., F.R.S., V.P.G.S., and Miss CATHERINE RAISIN, D.Sc. (Read June 7th, 1905.)

## [PLATE XLV—MICROSCOPIC ROCK-SECTIONS.]

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## I. INTRODUCTION.

ALTHOUGH so much has been written about serpentine during the last thirty years, a few points, as we think, still require to be cleared up. So we propose to describe in this paper, though it will mean some repetition of details already in print, the changes by which that mineral, or group of minerals, is produced from certain magnesian or ferromagnesian silicates. One of us published his first paper on this subject in the beginning of 1877, and since then he has been able to do some field-work on the rock on an average at least once a year. Of the specimens thus procured a number have been sliced for microscopic study, and others acquired by gift or purchase, so that his collection now includes about 180<sup>1</sup> sections of peridotites and serpentines, besides a large number containing more or less altered single grains of the parent-minerals. From the study of these, and of other specimens in the cabinets of friends, the opinions expressed in this paper have been independently formed, and it would have been written half a dozen years ago, if his arrangements had permitted him to visit certain localities, concerning which, as he believed, incorrect statements had been made. That task was kindly undertaken by the other contributor to this paper, who, in the summer of 1904, supplied the last link by visiting Sprechenstein and the Brenner district. Prior to this she had made a special study of the serpentines of

<sup>1</sup> It contains, among others: from Cornwall 57 specimens, from Scotland 16 specimens, and from the Alps 43 specimens; the remainder representing various localities in Europe, Asia, Africa, North America, and Japan.

Anglesey and of the Vosges, including the noted Rauenthal, and placed her collection, numbering over 270 specimens,<sup>1</sup> at the disposal of her collaborator. Under these circumstances Prof. Bonney is directly responsible for most of the microscopic work (though certain parts have been independently studied by Miss Raisin), while she is responsible for the field-work in the Vosges and the Brenner district.

Serpentine, whether this name cover one or more minerals, all minute, is formed by the alteration of certain magnesian or ferromagnesian silicates,—olivine and the non-aluminous pyroxenes and amphiboles. We purpose to describe, as briefly as possible, the changes in each one of these minerals, in order to discuss more particularly the genesis and significance of that variety of serpentine which is designated antigorite.

## II. SERPENTINE FROM OLIVINE.

Most of the typical serpentine-rocks are formed from peridotites by alteration of the olivine, which is their essential and dominant constituent. Thus, as the latter mineral was the first recognized parent of the former, the passage from the one to the other has been so often described that for the greater part of it a very brief recapitulation will suffice. We must, however, remember that the ratio of the two protoxide-constituents in olivine varies greatly, the name covering a series at one end of which is forsterite, where almost invariably the magnesia exceeds 50 per cent. and the ferrous oxide is well under 4 per cent.; and at the other fayalite, which contains little or no magnesia. The latter, however, obviously cannot be the parent of serpentine, and this mineral, so far as we have observed, is seldom produced from olivines rich in iron.

An ordinary olivine, in which the ferrous oxide is approximately from 6 to 12 per cent., passes through the following changes. Water makes its way along cleavage-planes or other cracks, forming serpentine from the adjacent parts and throwing down the rejected iron as minutely-granular magnetite in the dark, or hæmatite in the red, varieties. Thus the former constituent appears like a network, in which sometimes one set of strings runs rudely parallel for a time, and is slightly stouter than the other. These strings occasionally consist of fibres of serpentine, twisted almost as in a cord, but more commonly of flakelets, inclining to be fibrous, which are developed roughly at right angles to the surface of the crack. Some amount of freedom, we may remark, seems favourable to the latter mode of growth, for it can often be seen occupying minute cracks in a rock-slice, and the most conspicuously-fibrous forms, such as picrolite and chrysotile, usually occur in those of larger size. We leave for the present further description of the mineral, merely remarking that the iron-oxide is either deposited in the

<sup>1</sup> It contains, among others: from Anglesey 174 specimens, from the Vosges 70 specimens, and from the Brenner district 27 specimens.

original crack, thus marking its position, or as an imperfect coating on the strings, and that the process of alteration, after these have formed, seems to be checked for a time, since we find the meshes so often occupied with quite normal olivine. When this changes, the distribution of the iron-oxide is less regular, though it commonly forms a more or less central aggregate of granules; the serpentine is more fibrous and more variably arranged, being sometimes a little larger than that in the strings, sometimes so very minute that the mass between crossed nicols either behaves like a colloid, or exhibits the feeblest glimmer of specks, like the sky in parts of the Milky Way. An occasional result of the second change is to disturb the regularity of the network, and practically obliterate the structure of the olivine. The amount of iron, rendered visible by these changes, varies considerably, and no doubt depends on the percentage present in the original mineral; but it is sometimes more abundant in the strings than in the meshes, sometimes the reverse, and occasionally appears to remain in an ultra-microscopic form, giving a pale-yellow or green tinge to the one, the other, or both. In one specimen almost all the iron may be deposited in the original cracks; in another it may form a rather broad reddish-brown border to the interstitial serpentine. Colourless serpentine more commonly gives as polarization-tints whites or bluish-whites of the first order, the pale greenish-yellow variety producing generally the yellow or orange-reds of the same. This, we think, is not merely a result of size and thickness, for the two may occur in the same slice,<sup>1</sup> but is, we believe, due to the colouring-matter, which often does not produce any perceptible pleochroism.<sup>2</sup> Extinction is generally straight, but in both cases, and perhaps more often in the latter variety, it makes angles, up to about 15°, with the edge of the fibre or flake.<sup>3</sup> We have failed to note any other characteristic distinction of these varieties, if such they be.

In the diamantiferous breccia of South Africa<sup>4</sup> the olivine usually occurs in single grains, more or less converted into serpentine. In thin slices it is either colourless, or yellowish, or a pale green (the tint depending to some extent on the thickness of the slice); it rarely throws out granules of iron-oxide, and in changing to serpentine exhibits some variations. These have been described by the late Prof. Carvill Lewis,<sup>5</sup> whose statements one of us can corroborate, except that he has neither met with a good cleavage

<sup>1</sup> Of this I have more than one instance; one of the best comes from the compacter form of a rather streaky serpentine at Lankidden Cove, the Lizard. [T. G. B.]

<sup>2</sup> Some specimens from Anglesey in Miss Raisin's collection, in which the serpentine is a pale buff-yellow by ordinary light, show a pleochroism from that tint to pale green.

<sup>3</sup> Dana, 'System of Mineralogy' 6th ed. (1892-1900) p. 669, gives serpentine as a monoclinic mineral.

<sup>4</sup> My cabinet contains twenty-seven slices from Kimberley (some from over 1300 feet deep) and Newlands. As I have elsewhere pointed out, this rock, the so-called kimberlite, cannot be, as was once supposed, an altered peridotite. [T. G. B.]

<sup>5</sup> 'The Genesis & Matrix of the Diamond' 1897, pp. 14-16.

in the olivine nor found a minute fibrous hornblende in his own specimens so often as that excellent observer appears to have done. They contain, however, the two fibrous microliths which the latter refers to bastite,<sup>1</sup> though the dull-blue one is rare, and we doubt whether it is more than a local staining. The olivine alters into a minutely-fibrous serpentine, generally rudely perpendicular to, but sometimes parallel with, the outer surface, which forms a sort of thin shell, the interior being converted (some olivine often remains) into colourless fibres or even narrow blades sometimes about one twenty-fifth of an inch long (1 mm.). Their polarization-tints are generally the dull bluish-whites of the first order, but rise occasionally to the clear- or the orange-yellow (both tints may occur in the same slice), the extinction being generally straight, but occasionally oblique up to about 20°. In some grains these flakes form divergent tufts, which may develop longitudinally until the group roughly resembles a feather, the pinnules on opposite sides making angles of 22° to 24° (Pl. XLV, fig. 1). In one or two cases we find broad irregular flakes giving low polarization-tints, and notice that, in elongated grains, the flakes of the interior tend to lie parallel with the longer sides. We may, we think, conclude that the olivines in this rock are generally poor in iron, and may perhaps attribute the differences in structural change between them and the olivines in peridotites to their occurrence as isolated grains in a rather permeable material.

### III. AMPHIBOLE.<sup>2</sup>

The less ferriferous members of this group, as is well known, change, though not so readily as olivine, into serpentine. In fact, as might be expected, the ferromagnesian silicates with lime alter less rapidly than those without it. As this particular metamorphism has been rather fully discussed, we may pass briefly over it. The best-known instance is the serpentine of the Rauenthal, which in 1875 was asserted to have originated in great masses from an amphibolite, and this to exhibit a passage into a normal gneiss. One of us, in 1887, when publicity was given to that statement in an important English work, showed the former part of it to be only so far correct that the original rock (like some at the Lizard) had been a hornblende-peridotite.<sup>3</sup> This was confirmed, and the second part of it disproved, by the other of us in 1897.<sup>4</sup> The hornblende in the Rauenthal serpentine has been a slightly-ferriferous variety. Between its prismatic cleavages strings or blades of mineral serpentine (best examined in longitudinal sections)

<sup>1</sup> 'The Genesis & Matrix of the Diamond' 1897, pp. 14, 21.

<sup>2</sup> We have not been able to study the alteration of the rhombic amphibole, anthophyllite. One of us has been allowed to examine the specimens in the British Museum cabinet of slices, but these are practically unaltered, and a slice in his own collection (given to him by the late Mr. Rutley) is not helpful for this purpose.

<sup>3</sup> T. G. Bonney, *Geol. Mag.* 1887, p. 65.

<sup>4</sup> C. A. Raisin, *Quart. Journ. Geol. Soc.* vol. liii (1897) p. 246.

have apparently forced their way. Their structure is obscure, but they seem to be formed of fibres lying in the general direction of the cleavages. Their polarization-tints range from the white to the paler yellow of the first order, being perhaps a little lower than those of the strings in the altered olivine. We also find, at longer intervals, and with less regular direction, strings which probably mark the position of a very imperfect basal cleavage. The parts of the altered crystal between this network often show a minute fibrous structure, sometimes accentuated by interrupted lines of opacite. This yields low polarization-tints, but the most structureless parts produce hardly any effect on polarized light. Certain of the Lizard serpentines—those from Lower Pradanack, from south of Mullion, from the pit above Carnbarrow, from the mass below Kildown-Point Quarry, and from the northernmost outcrops on the Helston road—have all a general resemblance to the Rauenthal rock, though the olivine is occasionally, and the hornblende generally, better preserved. In the last-named Cornish example, however, one or two specimens of the latter mineral correspond exactly with those in the Vosges rock.

#### IV. ORTHORHOMBIC PYROXENES.

These ferromagnesian silicates form a series resembling that of the olivines. Tschermak distinguishes those in which the iron lies between 1 and rather more than 20 per cent., the magnesia generally ranging from 40 to 30 per cent., into enstatites and bronzites; and the remainder, in which the iron is above 30 per cent. and the magnesia correspondingly depressed, into hypersthènes and amblystegites. The first symptom of change, and it appears to be more readily developed in the former two, is the replacement of the usual cleavages parallel to the prism-faces by one parallel to a pinacoid. Varieties in which the percentage of silica is rather high and that of ferrous oxide is generally low have been called diacrasite, but in the absence of proof of chemical composition we shall apply the name bastite<sup>1</sup> to all forms occurring in serpentines. Signs of this change in the cleavage may be perceived when the olivine in a slice looks quite fresh, but conversion into serpentine takes effect more rapidly in the latter mineral.<sup>2</sup> Enstatite also alters into talc, but apparently with less ease, the reason for which will be noticed below.

The polarization-tints of enstatite (which usually are not so high as those of augite) are lowered by change through bastite to serpentine, and the cleavage-planes become, as it were, soldered together; but traces of them can be seen under the microscope, which, with the different kind of serpentinization, generally enable

<sup>1</sup> The optic axial plane, it will be remembered, is parallel in enstatite to the plane of easy cleavage, in bastite perpendicular to it.

<sup>2</sup> To this rule I have found two or three exceptions—for example, a serpentine from Carn Sparnack (Lizard), in which the bastite is replaced by a kind of steatite, and yet there is a fair amount of residual olivine. [T. G. B.]



us to identify the mineral. Where it originally contained a fairly-high percentage of iron, opacite (sometimes as belonites) is deposited more or less interruptedly along these planes, and thus indicates their position, where but for this record that would have been indistinguishable; but, when the percentage is low, we find only a few chance black specks or none at all. Even then, however, the mineral, instead of being practically colourless, sometimes has a pale-green tint (indicating no doubt a small amount of iron). It may then show a slight pleochroism, pale green with vibrations parallel with the cleavage-planes, and pale buff perpendicular to them. The polarization-tints of serpentized enstatite are generally the dull bluish-whites of the first order, rising occasionally to the pale yellow; grains cut nearly parallel to the cleavage-planes present a slight, but peculiar, wavy aspect, and with crossed nicols show glimmering patches of dull bluish-white on a dark ground—the result, no doubt, of some curvature in the structure.

Occasionally, as observed by Carvill Lewis in the diamantiferous rock of South Africa,<sup>1</sup> the enstatite (which contains 34·91 per cent. of magnesia and 4·99 of ferrous oxide, thus lying, according to Tschermak, on the border-line between enstatite and bronzite) alters into a fibrous bastite, one variety of which is a dark indigo-blue. In my slices of the diamantiferous rock the occurrence of this variety is doubtful, but it appears in a saxonite<sup>2</sup> (boulder) where the enstatite has a well-defined pinacoidal cleavage, but hardly any other signs of change.<sup>3</sup> At the same place a fragment of a coarse enstatite-rock was also found.<sup>4</sup>

In conclusion, we may mention one or two rather exceptional forms of change. In the altered bastite the fibrous structure may become more pronounced, or the mineral assume a slightly-pleochroic pale-brown instead of a green tint; or two species of it, a ferriferous and a non-ferriferous, may be present; or, very rarely, portions in a less advanced state may remain as small, slightly-interrupted prismatic rods (defined, of course, by the pinacoidal cleavage); or (as occurs in a dyke consisting practically of enstatite from south of Penrhyn Fadog, Anglesey<sup>5</sup>) the grains, slightly pleochroic, show polarization-tints ranging from the bluish-white to the pale yellow of the first order, are apt to be bent, and break up at the ends into a rather fibrous mass, of serpentinous aspect, which acts more feebly on polarized light, sometimes remaining dark between crossed nicols.

A poikilitic enclosure of olivine, so far as our experience goes, is rare, unless the crystals exceed the ordinary size (that is, about a third of an inch in diameter). At the Lizard it is practically absent, one or two slices only showing traces of it on a small scale,

<sup>1</sup> 'The Genesis & Matrix of the Diamond' 1897, pp. 19-21.

<sup>2</sup> Saxonite of Wadsworth, or harzburgite of Rosenbusch; that is, olivine-enstatite rock.

<sup>3</sup> I am doubtful whether the colour indicates more than a local staining due to the accidental presence of some mineral. [T. G. B.]

<sup>4</sup> See Proc. Roy. Soc. vol. lxx (1899) p. 231.

<sup>5</sup> Coll. C. A. R., No. 661.

as it is in altered saxonites and lherzolites from Ayrshire and Portsoy, from the Alps and the Apennines.<sup>1</sup> It occurs in Anglesey (exceptionally), in Aberdeenshire, and in the well-known rock of Baste in the Harz. In these cases, the enstatite seems to be rather readily changed into a whitish steatite, with a muddy brownish aspect under the microscope. The included olivine is usually a non-ferriferous variety.<sup>2</sup>

## V. MONOCLINIC PYROXENES.

These, when they are associated with the orthorhombic species, are much less readily converted into serpentine, and, as in it, the change is practically restricted to the varieties poor in iron (diopside and sahlite), apparently not occurring in the aluminous varieties (for example, ordinary augite). Specimens in our collections from Coverack in Cornwall, from one or two localities in the Alps, the Apennines, and the Vosges, retain the augite practically unaltered but the change is very well illustrated in the noted 'Eozoonal' rocks of Canada, which are mainly composed of calcite or dolomite, and malacolite or sahlite passing into serpentine.<sup>3</sup> A description of one specimen (from a wood by a road approaching Côte St. Pierre) will serve to illustrate the general character of the change. Here nodules of a whitish augite, more or less converted into serpentine (light green), are scattered in a marble containing irregularly-distributed grains of augite or serpentine, which sometimes occur in fairly-marked bands. The augite in a slice is present in more or less rounded grains, which form a continuous band at one end. It exhibits sometimes the characteristic, nearly-rectangular cleavage of an augite, but more often a single cleavage, not so close as in a diallage. At the edge of the band and in many detached grains it passes rapidly into serpentine. This occasionally forms along cracks (not always cleavage-planes) and its fibres are sometimes twisted as in a cord, but more frequently are growing at right angles to a surface or to an internal crack. These afford polarization-tints up to the yellow of the first order, but the inner part of the grains is occupied by a filmy mineral with very low tints, sometimes all but black between crossed nicols, which now and then is pierced by a

<sup>1</sup> These remarks, it must be understood, apply only to what I have myself seen and collected. [T. G. B.]

<sup>2</sup> The fusion-point in olivine is higher than in enstatite, but the different amounts of iron and the presence of water may lead to variations.

<sup>3</sup> Remarks founded on ten microscopic slices (coll. T. G. B.); see *Geol. Mag.* 1895, p. 292. As Mr. Coomaraswamy found forsterite with sahlite in the Tíree Marble (*Quart. Journ. Geol. Soc.* vol. lix, 1903, p. 91), and the two minerals (apart from cleavage) have a close resemblance, I wish to say that the possible occurrence of an olivine in these Canadian rocks has been present to my mind for several years (*Geol. Mag.* 1895, p. 297) and has not been forgotten on the present occasion. It is impossible to prove that forsterite may not have occurred or be represented by some residual granules; but I can say that, whenever these afford an edge from which extinction may be measured, this is oblique, and that bands of pyroxene with characteristic cleavage do pass rapidly into serpentine. [T. G. B.]

brighter 'thorn.' The scattered grains exhibit various stages of serpentinization, which most affects the thinner streaks. The fibres or flakes occasionally tend to be rudely parallel, but rarely, if ever, recall by their arrangement the almost rectangular cleavages so characteristic of augite when cut parallel with a basal plane. As we purpose to refer to the chemical significance of these changes, we quote analyses by the late Dr. T. S. Hunt: (I) of the pyroxene, and (II) of the serpentine from Grenville, where similar rocks occur with the so-called *Eozoon*.<sup>1</sup>

	I.	II.
SiO <sub>2</sub> .....	54.90	42.85
MgO .....	16.76	41.68
CaO .....	27.67	...
FeO .....	...	0.67
H <sub>2</sub> O .....	0.80 <sup>2</sup>	13.89
	<hr/> 100.13	<hr/> 99.09

Augite, as Miss Raisin found during her visits to the Vosges,<sup>3</sup> is not an unfrequent constituent of their serpentines. Certain of these, southward of the Rauenthal in the Central Vosges, are more than usually variable in composition. For instance, in one rather large mass to the north-east of Bonhomme, cropping out in craglets over a space of about 100 yards, the mineral structure varies from obscurely parallel to distinctly banded. In the latter case the bands, sometimes made conspicuous by a peculiar weathering and jointing, are often 1 or 2 inches thick. They are dislocated by a few slight faults, but the rock affords no other sign of mechanical disturbance. Microscopic examination shows the chief constituents to be picotite (fairly abundant), olivine (almost wholly converted into serpentine),<sup>4</sup> enstatite (partly changed), and augite. The last mineral has sometimes assumed the diallage-cleavage, and is often rather 'dusty'; cracks and cleavage-partings are occupied by very thin strings of serpentine, which often seems as if it had been formed by percolation from outside rather than by alteration of the adjacent mineral. Sometimes, however, the outer part of an augite-grain in contact with serpentine becomes rather fibrous. Curiously enough, the 'interleaving' with films of the latter mineral is least conspicuous in those grains which exhibit the two nearly-rectangular<sup>5</sup> cleavages. A slice (thin) from one of the bands (Pl. XLV, fig. 2) shows

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxi (1865) p. 68. It is rather remarkable that, as so much lime (to say nothing of the silica) has been removed, the change from augite to serpentine has left no trace in the adjacent calcite (or dolomite) of my St. Pierre specimens. [T. G. B.]

<sup>2</sup> In this case called 'volatile matter.'

<sup>3</sup> Undertaken for the immediate purpose of studying the noted Rauenthal serpentine. See this Journal, vol. liii (1897) p. 246.

<sup>4</sup> The structure is as described above, but the polarization-tints are rather bright; the two slices, however, are a little thick.

<sup>5</sup> In other words, those which are cut nearly parallel to the basal plane, and have not assumed the diallage-habit.

a granular structure, and consists of a pale augite (the more abundant), fairly clear, though setting up a diallage-cleavage, and a very clean serpentine which often produces little effect on polarized light, but sometimes gives low tints, revealing traces of a platy cleavage and generally extinguishing obliquely with it. This fact, the residual granules of augite in the serpentine, and the way in which the latter occasionally seems to soak like water into a grain of the former, justify us in regarding the one as an alteration-product of the other.

Miss Raisin obtained a rather remarkable pyroxenic serpentine from the Fellingengenkopf in the Southern Vosges. In the hand-specimen it appears to be a dark serpentine,<sup>1</sup> mottled with a paler green (perhaps merely the thin edges of fractures), and spotted with fairly-numerous pale brass-yellow to whitish grains with an undulating platy cleavage. The microscope shows the following minerals:—(a) grains of an iron-oxide (not abundant); (b) grains with a rather wavy parallel cleavage, indicated by granules or short belonites of opacite; polarization-tints whitish to a distinct dull blue; extinction probably straight, but difficult to measure because of curvatures; (c) a dusty-brown fibrous mineral, alternating in flakes with, and apparently passing into, the last one, and giving, when this can be seen, marked pleochroism and rather bright polarization-tints, with straight extinction; (d) a colourless mineral associated with small grains of a granular, or fibrous granular, light honey-brown mineral, which is probably an augite, and seems to pass into an almost amorphous aggregate acting very feebly on polarized light. No structure characteristic of olivine occurs in the slice and, notwithstanding the megascopic aspect of the rock, two varieties of enstatite with some augite seem to be more probably its original constituents. Bent cleavages and other irregularities in this specimen suggest slight mechanical disturbance.

A slice of another rock from the same locality contains augite in small grains or prisms parted by very narrow films of apparently-amorphous serpentine. These are obviously residues of larger grains, which occasionally suggest slight mechanical disturbance. We also find minute flecks scattered about the slice, with little granular fibrous and rather dirty-looking spots. These, when highly magnified, prove to be augite, and occur like islands in the serpentine which (with some opacite and grains of iron-oxide) occupies most of the slice, and produces no sensible effect on polarized light. Thus augite, which now is the only anhydrous silicate recognizable in the rock, seems to have been formerly very abundant.

In a third specimen from this locality the greater part of the slice suggests, by the disposition of the opacite, the former presence of an olivine; the structure of the serpentine is minute and its action on polarized light rather feeble, but it seems locally to become irregularly fibrous. Here and there spots occur free from opacite, but containing numerous small fibrous flakes of a

<sup>1</sup> Not unlike the black serpentine of the Lizard, the Apennines, Corsica, etc.

mineral with a higher refractive index than serpentine, and with whitish polarization-tints, which, as will be seen in the next section, has some resemblance to antigorite. A few of the flakes are slightly iron-stained, and they give brighter polarization-tints. These clear spots presumably indicate the former presence of some kind of pyroxene, but retain no trace of its original structure.

## VI. ANTIGORITE-SERPENTINE.

Having thus described the forms of serpentine which can be shown to have been produced from olivine, hornblende, augite, and enstatite, we pass on to that called antigorite and the circumstances of its occurrence. It was named from the Val Antigorio in Piedmont, but it has been described in considerable detail by Dr. Hussak<sup>1</sup> from Sprechenstein on the Brenner. He, however, had not visited the locality, but received his specimens from a friend. The district was examined by Miss Raisin in the summer of 1904, so that, though one of us has seen the Val-Antigorio rock, we will deal more particularly with that from the Tyrol. Antigorite is defined<sup>2</sup> as a light-green mineral, occurring in scales with a perfect cleavage of the mica-type. Sections at right angles to this perfect cleavage are lath-shaped. They give straight extinction, and are distinctly pleochroic; leek-green when the short axis of the nicol is parallel to the cleavage-cracks, colourless when the short axis is at right angles to these cracks. The double refraction of this mineral is slight and negative, the negative bisectrix agreeing with the vertical axis. Cleavage-flakes show, in convergent light, the optic picture of a biaxial crystal with small axial angle. The dispersion is well marked. The following analyses are quoted: (I) of the Sprechenstein mineral; (II) of that from the Val Antigorio, in which apparently a little iron-oxide still remained; (III) of the schistose serpentine (bulk), and (IV) of the massive serpentine (bulk)—both from Sprechenstein.

	I.	II.	III.	IV.
SiO <sub>2</sub> .....	41·14	41·58	40·55	40·90
Fe <sub>2</sub> O <sub>3</sub> .....	3·01	7·22	10·40	7·68
Al <sub>2</sub> O <sub>3</sub> .....	3·82	2·60	2·70	2·08
CaO.....	0·40	.....	4·40	0·30
MgO .....	39·16	36·80	33·59	37·45
H <sub>2</sub> O .....	11·85	12·67	9·32	12·15
	<u>99·38</u>	<u>100·87</u>	<u>100·96</u>	<u>100·56</u>

The two mineral analyses, so far as they differ from that of a perfectly-typical serpentine (SiO<sub>2</sub>=44·1, MgO=43·0, H<sub>2</sub>O=12·9) probably do this in consequence of the replacement of magnesia by

<sup>1</sup> Tschermak's Min. & Petrogr. Mitth. n. s. vol. v (1883) p. 61.

<sup>2</sup> Quoted in substance from the excellent summary of the original paper in Dr. J. J. H. Teall's 'British Petrography' 1888, pp. 112-15.

ferrous oxide and the impossibility of getting the material quite pure. The bulk-analyses are not unfrequent among serpentines. Dr. Hussak also detected in the Sprechenstein serpentine residual grains of sahlite, of a brownish diallage, tale (often associated with the latter), a green chlorite and staurolite (in small round grains, or, more rarely, as columnar crystals). He calls attention to slight differences between the compact and the schistose serpentines, pointing out that the former consist mainly of antigorite-scales, which are arranged in two sets of parallel planes meeting at an angle of  $90^\circ$ , so as to produce a netting-like (*gestrickte*) structure. 'In short, the sahlite-grains are related to the antigorite-serpentine, exactly as the olivine-grains to normal serpentine, and the hornblende-grains to the serpentine with lattice-structure.' So 'three definite types of structure of genetic importance are now recognized,' one of them being serpentine with netting-like structure (*gestrickte struktur*) or augite (antigorite)-serpentine.

One of us has, more than once, put on record his doubts of the validity of this induction.<sup>1</sup> Dr. Teall himself expressed a suspicion that the author had not made sufficient allowance for the effect of mechanical disturbances. Prof. Rosenbusch<sup>2</sup> intimated in 1898 that the above generalization required some limitation, and Prof. G. A. J. Cole<sup>3</sup> in 1902 cautioned the student against hasty recognition of this netting-structure.

The British-Museum Collection of minerals contains a specimen of antigorite from the Val Antigorio, a slice from which, by the kindness of the authorities, has been cut for examination. It was so 'flaky' that the section had to be made parallel to the cleavage, on which surface spots with a faint metallic gleam were discernible, like the ghosts of enstatite. These could be distinguished under the microscope by a slight difference in structure from the rest of the groundmass, which consisted of very minute irregular flakes, with the usual bluish-white polarization-tints and a slightly 'thorn-like' aspect. No pleochroism is perceptible, and this mineral (antigorite) is much less characteristic than in the specimens from Sprechenstein. The most conspicuous objects in the slice are a few little tufts of a fibrous mineral, like actinolite, but with an extinction-angle ranging up to  $35^\circ$  (? wollastonite). Three points are noteworthy in this type-specimen: one, the extreme minuteness of the antigorite<sup>4</sup>; another, that the rock has been greatly affected by pressure; and the third that it originally contained, certainly enstatite, and so probably more olivine than augite.<sup>5</sup>

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lii (1896) p. 453 & *ibid.* vol. lix (1903) p. 59.

<sup>2</sup> 'Elemente der Gesteinslehre' 1898, p. 525.

<sup>3</sup> 'Aids in Practical Geology' 4th ed. (1902) pp. 149 & 180.

<sup>4</sup> To this I can find a parallel in more than one specimen from other localities in my collection. [T. G. B.]

<sup>5</sup> F. Becke, in *Tschermak's Min. & Petrogr. Mitth.* n. s. vol. xiv (1894-95) p. 271, describes the formation of antigorite in a rock which was substantially a dunit, occurring near Windisch Matrei in the Stubachthal, and calls attention to the frequent occurrence of the mineral in pressure-modified serpentines.

Quite recently two closely-allied minerals—pseudo-regular antigorites, to use his phrase—have been described by Axel Hamberg.<sup>1</sup> One, from Persberg in Wermland, occurs with magnetite, chlorite, and calcite, in cubic form, measuring from 2 to 5 millimetres along the edge, with cleavage in three directions, one strong; greenish-white in colour, and pearly in lustre; not harder than gypsum. The other from Kograbe, Nordmark, is a hexagonal, easily-cleaving mineral, yellow-brown in colour, only slightly pearly, with a larger axial angle and more transparent than the other.

Analyses are given as follows:—

SiO <sub>2</sub> .....	43.68	42.90
Al <sub>2</sub> O <sub>3</sub> .....	0.34	0.51
MgO .....	38.94	39.19
FeO.....	4.18	3.90
MnO .....	trace	trace
H <sub>2</sub> O.....	12.03	12.30
F <sub>2</sub> .....	.....	0.97
	<hr/>	<hr/>
	99.17	99.77
	<hr/>	<hr/>

He remarks that these are practically analyses of an ordinary serpentine (H<sub>4</sub>Mg<sub>3</sub>Si<sub>2</sub>O<sub>9</sub>) with some replacement of MgO by FeO, and that this mineral seems to fall into two groups—one fibrous, typified by chrysotile; the other leafy, by antigorite. That, as will be seen, quite accords with our own conclusions, but we doubt whether a hard-and-fast line can be drawn between them.

## VII. THE SPRECHENSTEIN SERPENTINES.

Sprechenstein is near the town of Sterzing, on the Brenner road. The serpentine can be traced obliquely up the steep wooded slopes east of the Eisack Valley, the largest mass exposed being in a crag which forms a slightly-convex projection at the foot of the hill, while smaller outcrops are visible higher up. This crag is largely composed of a hard, rather tough, harsh-feeling serpentine, pale green on fresh fractures, weathering to a dark green, sometimes purplish on smooth surfaces. The rock is compact, often rather regularly jointed, so as to form big rectangular blocks. Not a little, however, especially at the northern part, is conspicuously schistose, and the imperfect wavy cleavage-planes often enclose lenticles of the more compact serpentine. The schistose parts are generally not quite so hard or rough to the touch as the compact, are less granular-looking, and a little more mottled with lighter-coloured spots. They are frequently patched or veined with a whitish mineral. A much-crushed gneiss crops out to the north, separated from the serpentine-crag by an interval of the wooded slope. A mass of vein-stuff about 4 feet thick, a description of which is reserved for the present, borders the serpentine, which for the first 20 feet is conspicuously schistose. It then becomes a

<sup>1</sup> Geol. Fören. Stockholm Förh. vol. xxvi (1904) pp. 67-83.

massive and jointed rock, extending (partly within a fence) for about 100 yards.

A slice cut from the edge of the serpentine, adjacent to the vein-stuff, proves to be mainly composed of a mica-like mineral in slightly-irregular flakes, from about .01 inch downwards, all but colourless and without perceptible pleochroism, giving low polarization-tints (bluish-whites of the first order) and straight extinction; little streaks or patches being occasionally replaced by a carbonate allied to dolomite. Here and there are a few fibres with higher tints, and extinguishing obliquely, probably actinolite. The mica-like minerals sometimes exhibit an approach to foliation, sometimes to rectangular arrangement; but closer examination shows this, where it is not illusory, to affect the whole slice and to have no relation to any original mineral structure (Pl. XLV, fig. 3).<sup>1</sup> Iron-oxide occurs in clustered or trailing granules, and this occasionally includes or is pierced by the mica-like mineral, giving a minute 'ophitic' structure (fig. 1). The rock has unquestionably been modified by pressure.

Fig. 1.—*Antigorite, showing 'ophitic' structure in magnetite* (from a Riffelhorn specimen).



[Magnified 30 diameters.]

Two slices have been cut from specimens taken farther in the schistose zone. In these the flakes are sometimes very slightly

<sup>1</sup> Hereafter, for brevity, we shall refer to this as 'thorn-structure,' a name which we gave it for purposes of reference. I first came across it in a serpentine to the east of Andermatt, in 1878, and we found it occasionally in Anglesey. [T. G. B.]



larger, but there are no differences of any importance. A slice from the more massive serpentine only differs in not having the granular iron-oxide so much 'trailed out,' and in containing a number of minute granules, giving fairly-bright polarization-tints, which possibly represent residual augite.

The hillside then slightly recedes for from 200 to 300 yards, and a path across it (leading up to the old castle) passes some serpentine, a craglet of which exhibits crushed zones and a bluish weathering. Another outcrop is obviously much crushed, but this may not be *in situ*. Micaceous gneiss and schist also crop out on the slopes, the castle standing on a knoll of stronger gneiss. Miss Raisin made two other traverses across the serpentine, one about the level of the castle, and one higher up the slope. On the former she found the serpentine in bosses, near some small cottages, much crushed and including a crushed talc-schist; and on the upper she crossed an interesting vein about  $3\frac{1}{2}$  feet long and 6 inches wide—showing, like the surrounding serpentine, much crumpling.

The 'crushed flaky mottled rock, by the path to the castle,' exhibits a rather crumpled foliated structure, and consists of the following:—a colourless mica-like mineral; black iron-oxide in more or less irregular patches; and a fairly-large amount of slightly-greyish or brownish granules, sometimes forming thin streaks. The flakes of the first are commonly about  $\cdot 015$  inch long, but occasionally almost double this. The polarization-tints belong to the first order, and rise to yellow or brownish orange, but smaller flakes of the bluish-white variety are associated with it; though these are generally the smaller, we doubt whether the difference is due to size alone. The slice also contains, though very locally, a third variety, the tints of which never rise above a very dull dark blue. The granular mineral is apparently residual augite, the crystals of which have been crushed almost to powder.

The talc-schist collected on the lower traverse proves, on microscopic examination, to be a matted mass of that mineral, generally resembling those described from the Gorner Grat<sup>1</sup> and Anglesey,<sup>2</sup> but it contains a rather large amount of a carbonate (? magnesite) often with flecks of limonite deposited in its cleavages. The crushed serpentine taken on the higher traverse shows the very faintest trace of pleochroism (straw-coloured to pale dull green), and consists of (*a*) the usual mica-like mineral, occasionally very minute: sometimes showing 'thorn-structure' and sometimes a streaky foliation, indicative of crushing, in which the polarization-tints become slightly higher than usual; (*b*) the usual granules and grains of iron-oxide; and (*c*) a fair number of granules or small fragments of crystals, which resemble residual augite, although their extinction-angles, so far as they can be measured, agree better with hornblende. The slice cut from the vein affords marked indications

<sup>1</sup> Geol. Mag. 1890, pp. 538, 540.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 44.

of crushing, and consists of calcite (the most abundant), a colourless acicular hornblende (clearly secondary), some residual granules which may be augite, and flakes (not numerous) of the low-tinted serpentine.

Turning now to the vein already mentioned, we find the matrix to be a dolomitic calcite, and the greyish material embedded in it to be a rather prismatic mineral, resembling an augite, granules of which are apparently enclosed, though these afford only low polarization-tints like the flaky serpentine and extinguish at small angles.<sup>1</sup> This suggests that we have here an altered condition of the latter mineral, but that, owing to the absence of some necessary factor, it has not yet become antigorite.

### VIII. THE SATTELSPIITZ DISTRICT.

The Sprechenstein outcrop, according to Dr. Hussak, is the westernmost of a zone which extends, with some interruption, from the Sattelspitz, at the head of the Sengesthal. Of this mountain Miss Raisin was not able to make more than a hasty examination, but she observed that the crags of green serpentine cropping out on the slopes of its broad combe exhibited a schistose structure, with a rough east-to-west strike. She collected specimens from the screes and abundant débris below, six of which have been sliced. All show the usual flaky mineral (antigorite) with more or less of the 'thorn-structure,' and occasional streaking along a line of crush. They differ only in the greater or less amount of 'ophitic structure' and of residual augite. One slice contains this mineral in fair-sized grains of a pale brownish colour, which sometimes exhibit a well-marked diallage-cleavage. The antigorite shows a slight tendency to follow the latter, but none whatever in regard to any prismatic augite-cleavage.

Beyond the Wilde Kreuzspitze (northward of the Sattelspitz) is the Burgumerthal (a tributary of the Pfitschthal, joining the Eisack just below Sterzing). On the sides of the valley serpentine crops out, apparently intrusive, among gneiss and schist. Specimens were collected from the screes below, near the Sterzinger Hütte, from which three slices have been cut. One consists of some crushed iron-oxide (occasionally showing the ophitic structure) and a little residual augite, but mainly of the clear, colourless, mica-like antigorite, with the usual low polarization-tints, the length of the flakes running up to about .03 inch. Foliation is conspicuous, with here and there sharply-arched flexures (Pl. XLV, fig. 4). Another specimen contains a considerable amount of residual augite, and rather less of a dull-yellow granular mineral. The augite, which looks as if it had been somewhat affected by pressure, is slightly banded, and, where most abundant, forms

<sup>1</sup> This abnormal extinction seems not unfrequent in the residual augite of these Alpine serpentines with antigorite, and is to some extent comparable with the well-known change of the former mineral into uralite.

about half of the rock; the flakes of the mica-like mineral are slightly shorter and stouter than is usual, and its low polarization-tints are of a more 'chalky' white. Its extinction sometimes appears slightly oblique, which, however, may be due to strain. It can hardly be anything but antigorite, but it occasionally resembles one variety of chlorite. The yellow mineral is perplexing: the granules have no regular outlines, though one or two seem slightly elongated. Their general aspect suggests a rather impure epidote, but they remain dark between crossed nicols.<sup>1</sup> We must be content with suggesting the possibility of perovskite. A third contains a rather fibrous mineral, associated with the antigorite, which, in polarization-tints, extinction, and general aspect, corresponds best with actinolite. There is also a vein occupied by calcite, probably rather dolomitic.

A specimen collected from a block in the stream near Mauls, below the Sengesthal, is so very like the first of the three from near the Sterzinger Hütte, that it is enough to say that the flakes of antigorite are slightly smaller and the folding is not quite so conspicuous.

#### IX. THE MATREI SERPENTINE.

Here, on the northern slope of the Brenner Pass, a much-crushed opicalcite has been worked in a large quarry, on the steep hillside near the hamlet of Pfons. The specimen examined consists so largely of carbonates—calcite with some dolomite—that we are unable to draw any conclusion from it, the flaky mineral presenting more resemblance to an ordinary mica. The most interesting outcrop of serpentine is at the northern end of Matrei village. Here the river sweeps in a more than semicircular curve round the base of a crag crowned by a castle. On its southern face is serpentine, apparently intrusive in a muddy-looking limestone, the horizontal strata of which are displaced by slight faults. Difficulties of access interfered with close examination, and made it impossible to obtain a junction-specimen, but slices have been examined from the two rocks at the distance of a few yards and from other parts of the crag. Of the former, one is a very fine-grained dolomite, which might either come from the Trias or be a pulverized member of the calc-mica-schist group, to which several other specimens, though modified by pressure, probably belong. Miss Raisin found the serpentine to be blackish or invisible green in colour, with a resinous lustre; brittle, much jointed, almost crackled; more compact and smooth-looking on a fresh fracture, and softer than the Sprechenstein rocks; showing occasional small weathered enstatites, and altogether more like a 'black' serpentine from the Lizard. A specimen from behind a small shrine proves to be greatly crushed and altered, consisting of a minute fibrous mineral, resembling talc, but with duller polarization-tints, in which (as in the talc-

<sup>1</sup> Occasionally a small grain seems to produce some effect, but this may be due to the interposition of a flake of the mica-like mineral.

schists of the Gorner Grat) we find a little of a flaky greener mineral, faintly pleochroic in that colour, and producing but small effect on polarized light. From the north of the castle comes a specimen, not much crushed, which has been an olivine-enstatite rock<sup>1</sup>; the serpentine replacing the former mineral produces more effect on polarized light in the 'strings' than in the meshes, but it approaches once or twice the antigorite-'habit': that replacing the enstatite needs no special description. Of four specimens from a crag and blocks near a waterfall: one, resembling the rock from near the shrine, but with brighter polarization-tints, is a variety of talc-schist; another is rather banded; flakes producing dull white polarization-tints<sup>2</sup> dominating in one part, a very minute mineral—perhaps the same—in another, and in a third, a mineral affording rather bright polarization-tints, with apparently-straight extinction—perhaps a peculiar form of antigorite. The other specimens, which contain normal antigorite, do not call for any special remark—except that one is about as much crushed as some of the slaty serpentine described in the next section.

Thus the serpentines of the Brenner district prove (a) the existence of antigorite (including the variety with slightly-higher polarization-tints) in close association with augite, but without any relation to its prismatic cleavages; (b) that pleochroism is not an essential property of antigorite, but probably depends on the accidental presence of some colouring-matter; and (c) that we have failed to find any mineral resembling staurolite.

#### X. OTHER ALPINE SERPENTINES.

The Alpine serpentines, as one of us has more than once pointed out, can be arranged in two fairly-distinct groups, namely, altered olivine-enstatite rocks, with or without some augite, and olivine-augite rocks often rich in the latter mineral. He has found the former *in situ* on the Col de Cristillan, the Col de Sestrières, the Mont Genève, in the Val d'Anniviers, and once or twice in the Central Pennines, near Davos, at more than one place between Tiefenkastrall and the Julier Pass, and by the Silser See:<sup>3</sup> the

<sup>1</sup> This difference in the parent-rock is noticed by Dr. Hussak, and in Zirkel's 'Lehrbuch der Petrographie' 2nd ed. vol. iii (1894) p. 395. We have, however, noted some residual augite in a second (less crushed) specimen from near the shrine. It also has contained olivine and perhaps enstatite.

<sup>2</sup> This also, as in the specimen described above, is suggestive of a chlorite; but, on the whole, I incline to regard it as an abnormal antigorite. A specimen in Miss Raisin's collection from Cerig Moelion, Anglesey, with much of this mineral, some altered enstatite, and residual diallage confirms this view. [T. G. B.]

<sup>3</sup> But I found, south of the Bernina, at the junction of the glens from the Muretto and Canciano passes, a serpentine consisting largely of antigorite (polarization-tints up to yellow) with a fair amount of residual augite (some stained sienna-brown) and a little of a chlorite; the serpentine also above Lanzada (with 'asbestos'), on the west side of the latter pass, contains residual augite and antigorite in rather foliated flakes, sometimes '04 inch long, the polarization-tints ranging up to the pale yellow of the first order. [T. G. B.]

other is especially common in the Pennine Alps between the Col du Collon and the Simplon Pass, and occurs also near Cogne. Alpine serpentines are sometimes so much affected by pressure as to become perfectly slaty. Such he has found near the Col de Vallante (Viso), at Verrex in the Val d'Aosta, on the Gorner Grat and at the base of the Riffelhorn, where flakes can be obtained no thicker than a postcard.

For the microscopic structure of the first group we may refer to descriptions already published.<sup>1</sup> Except for occasional effects of pressure, they do not differ from serpentines of similar composition from Scotland, Cornwall, and the Apennines. For the second group also, if that so abundant about the head-waters of the Visp be accepted as an example, we may refer, in most cases, to what is already in print. This serpentine is usually harder to scratch or to break,<sup>2</sup> a little more granular to the eye, and rougher to the touch than that obtained at the Lizard, and very rarely, if ever, shows any trace of enstatite. Even when most compact, it breaks with less ease and with a less curd-like fracture than the other serpentine. But even then the microscope generally reveals some minute residual grains of augite, while the more granular kinds are rich in that mineral. Many of them are megascopically identical with specimens brought by Miss Raisin from Sprechenstein.

We will first briefly notice five specimens, hitherto undescribed, from the upper part of the Saasthal. The first, from the smallest of the three well-known great boulders on the valley-floor above the Mattmark Hotel, must occur *in situ*, either on the eastern face of the Strahlhorn or in a spur running from it to the north-east. The microscope shows the rock to have suffered from pressure, to contain more than the usual amount of magnetite (with a little pyrite), much augite, both residual and in larger, dusty, brownish grains frequently showing diallage-cleavage—perhaps making up altogether one-fifth of the slice,—while the rest consists of the two varieties of the mica-like mineral (antigorite), as mentioned above, the one with bright tints, generally, but not always, the larger, perhaps a little less definitely cleaved, and certainly sometimes giving a slightly-oblique extinction up to about  $10^{\circ}$  or  $12^{\circ}$ . In

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlv (1889) p. 81 & Geol. Mag. 1880, p. 538.

<sup>2</sup> Its hardness is generally higher in the scale than that of the other variety, sometimes nearly a degree. As Miss Raisin observed in the Brenner district (p. 701) the more schistose specimens are less hard and rough than the others, [Since this paper was read I have again visited the Saasthal, and examined many boulders on the moraine of the Fee Glacier and in the valley above Almagell (that is, representing another set of outcrops). The waterworn blocks commonly have a characteristic smooth, rather mottled surface (pale and dark green); they are much tougher than the ordinary serpentines, and feel so much harder and (commonly) 'harsher' in the hand, that I believe I could distinguish them blindfold. I failed to find any specimen of the ordinary (olivine-enstatite) serpentine. I may say that the work of the past two years has proved to me that augite has been, at any rate sometimes, a still more abundant constituent in this second group than I formerly supposed.—T. G. B.]

one place the two varieties form a nest in the heart of a grain of diallage, piercing it in all directions irrespective of the cleavage.

The second specimen, labelled in the field 'serpentine (streaky)', came from a block on the right lateral moraine of the Fee Glacier, and is probably *in situ* somewhere near the Hinter Allalinhorn.<sup>1</sup> The rock has been somewhat affected by pressure; about four-fifths of it (Pl. XLV, fig. 5) is augite, clear to 'dusty',<sup>2</sup> with only occasional traces of diallage-cleavage, and the remainder (besides iron-oxide) consists of the two mica-like minerals, the larger generally (though not always) affording the yellow polarization-tints; both, so far as measured, giving straight extinction. They are intimately associated with the augite, but their general direction is obviously at right angles to that in which pressure has acted.<sup>3</sup> There is one grain, about .06 inch long, which gives the dull but rich blue polarization-tints already mentioned.

The third specimen, from the terminal moraine of the same glacier, may have come from either the above-named range or a spur running northwards from the Allalinhorn to the Langefluh. The rock is modified by pressure, and consists (besides iron-oxide) almost wholly of a rather confused mass<sup>4</sup> of colourless mica-like minerals, which afford both kinds of polarization-tints, the brighter on the whole dominating, and both giving, so far as measured, straight extinction. We find, however, some irregular patches of flakes, which have a slightly-stronger cleavage, show a tinge of brown with transmitted light, and are feebly pleochroic (very pale green with parallel vibrations, and rather straw-coloured with perpendicular).

The fourth specimen (labelled 'rather crushed') is from the same moraine, and is found to be (apart from the iron-oxide) a mass of mica-like flakes, varying in length up to about .01 inch, and exhibiting the two usual polarization-tints of the first order, the yellow dominating. Parts of the slice, however, show an approach to 'thorn-structure'; others streaky patches of flakes, arranged so as to produce a nearly-uniform colour and simultaneous extinction. Two grains, showing a cleavage like that of augite, but acting feebly on polarized light, may represent remnants of that mineral.

The last specimen, 'from the moraine of the Schwarzenberg Glacier,'—a very typical one of the rather lighter-green hard serpentine, though not very fissile in the hand-specimen, is shown by the powdered magnetite to have been much crushed. It is

<sup>1</sup> The mountains from the Allalinhorn to the Egginerhorn are coloured as serpentine in the Swiss Geological-Survey map, but Grüner Schiefer also occurs in the range. [T. G. B.]

<sup>2</sup> The apparent dust, under a high power, often resolves itself into minute clear films.

<sup>3</sup> Each of these statements may be made of a schistose serpentine (rather richer in magnetite) but recently sliced. It was collected in 1889 from the old moraine on the left bank of the Findelen Glacier, where it was rather common. This leads me to suppose that it comes from the Gorner-Grat mass—probably from somewhere near its north-eastern end. [T. G. B.]

<sup>4</sup> The confusion may be due to the accidental direction of the slice, which, as the rock showed no very definite structure, was cut to suit convenience.

composed of flakes, rather irregular in outline, of the usual mineral, without any distinct orientation, which give the faintest possible trace of pleochroism (green to buff) and polarization-tints ranging through the first order, once or twice reaching the violet of the second order.

Specimens of this kind of serpentine from the summit of the Riffelhorn have been already described,<sup>1</sup> so it will suffice to repeat that they (and one from the moraine of the Gorner Glacier) contain the mica-like minerals with the lower and the higher polarization-tints, and though the latter are generally, they are not invariably, the larger. One slice includes only the dull-tinted, and all of these show residual augite, sometimes clear, sometimes dusty, occasionally with diallage-cleavage; in the flakes extinction is usually straight, but, as stated, there are exceptions which sometimes at least may be actinolite, for they apparently have a slightly-higher refractive index. Magnetite, and occasionally awaruite, is present; crushing, crumpling, and the ophitic structure have been noticed. Additional work has convinced the author of the original description that augite has been even more abundant in these rocks than he had supposed (for he fails to find any certain trace of other ferromagnesian minerals), and that it has frequently produced the above-mentioned flaky mineral. He pointed out (in 1896) its resemblance to antigorite, as then described, and has now no hesitation in assigning that name to at least the variety with low polarization-tints, between which and the other one he has not yet found any valid distinction.<sup>2</sup>

## XI. SLATY SERPENTINES.

These are so schistose, as to resemble green tiles or slates, the broken surface of which affords no clue to the original composition of the rock. The least fissile of them comes from the Fee Alp, near Saas, where it forms a dyke in the calc-mica-schist series.<sup>3</sup> Two slices have been cut from it, one of which (a little thicker) shows a slightly-stronger tint of green with parallel than with perpendicular vibrations. They contain the usual iron-oxide (with occasional ophitic structure) and a streak of a granular mineral (? a carbonate), but are mainly composed of the two mica-like minerals, variable in size, though generally rather small, and with so marked a structure that the slice exhibits fairly-definite streaks of colour (generally pale yellow) where the former makes an angle of 45° with the vibration-planes of the crossed nicols. Here also size and thickness,

<sup>1</sup> E. Aston & T. G. Bonney, *Quart. Journ. Geol. Soc.* vol. lii (1896) p. 452.

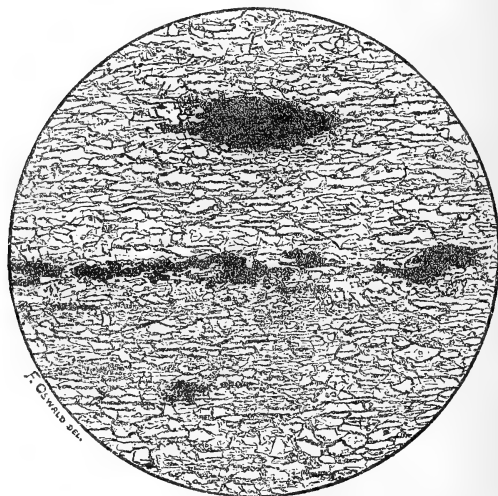
<sup>2</sup> A specimen collected in 1889 'from old moraine of Furggen Glacier' (it might come from the Furggen Grat or the northern spur of the Matterhorn on the whole resembles a serpentine from olivine, but contains no certainly-recognizable bastite or other residual mineral, and is almost wholly composed of rather minute antigorite, with a structure ranging from 'thorn' to streaky.

<sup>3</sup> The Alpine serpentines, indeed all that I have seen, very rarely form dykes. [T. G. B.]

though favourable to the production of higher tints, do not appear to be the only factors. Extinction is generally straight.

The slabby serpentine from the Gorner Grät has been so fully described,<sup>1</sup> that we need only repeat that it is a felted foliated mass of rather minute minerals like those already described, the highest polarization-tints being the clear yellow of the first order. The author then (1890) suggested the possibility that part at least might be antigorite, and would now identify it without hesitation, for a very faint pleochroism is occasionally perceptible.

Fig. 2.—*Slaty serpentine from the Gorner Grät, sliced generally parallel with the microfoliation.* [Magnified 50 diameters.]



[Geol. Mag. 1890, p. 537. We are indebted to the Editor, Dr. Henry Woodward, F.R.S., for the use of the block.]

As the augitic serpentine of the Riffelhorn is very abundant in that neighbourhood we should naturally suppose those slaty serpentines on the Gorner Grät to be modifications of it.<sup>2</sup> But one of us accidentally discovered the need of caution. Probably on his third visit (in 1860), certainly some years before he collected rocks

<sup>1</sup> Geol. Mag. 1890, p. 533. Miss Raisin has specimens (not quite so slabby) from this locality and from near the Lower Théodule hut. Both consist almost wholly of antigorite (without residual augite): the former might have come from Sprechenstein, in the latter the mineral is rather smaller.

<sup>2</sup> They are also a little harder than ordinary serpentine. A slaty specimen from a small pit by the path from the Riffelalp Hotel to the Findelen Glacier, contains narrow and thin blades, up to about three-quarters of an inch long, of a pale-green mineral which proves to be actinolite.



except as mementos or samples of anything unusual, he brought away a bit not so big as his thumb from the Riffelhorn. He has forgotten the exact locality, but thinks that it probably came from rather low down on the northern face of the peak. A short time ago, as it seemed a little different from his other specimens, he had it sliced, and found it to be not only practically unaffected by pressure, but also to exhibit most distinctly the peculiar mesh-structure of serpentine derived from olivine, and to contain a little altered enstatite. The replacing mineral in the 'strings' (clotted occasionally with black iron-oxide) affords low polarization-tints in the first order (rarely reaching pale yellow) and that in the interstices is almost inert, as it also is in the replaced enstatite. The occurrence of this saxonite, in such close association with an augite, shows that at present we could not safely claim the latter rock as the invariable parent of a fissile serpentine.<sup>1</sup>

In a slaty serpentine collected 'a short distance above Verrex, Val d'Aosta,' the iron-oxide indicates great crushing and the bulk of the slice consists of a felted foliated mass of the usual mica-like mineral with low polarization-tints, though it is large enough in places (about .025 inch long) to give the higher colours if they depended on size alone. The slice also contains a few small streaks (probably formed in cracks) of a rather mica-like colourless mineral in stoutish flakes (not exceeding .01 inch) which show pale-yellow (inclining to buff) polarization-tints and give straight extinction.

A still more slaty serpentine (about a quarter of an inch thick) comes from near the Col de Vallante (Viso district).<sup>2</sup> It is a felted foliated mass (with slight 'rucking' or 'stepping') of rather minute flakes, and a little crushed iron-oxide, which shows a faint tinge of the usual pleochroism, and affords, when placed at an angle of 45°, as mentioned above, fairly-bright polarization-tints occurring streakily—the clear yellow of the first order to the blue of the second, rather bright in one part. Some longer flakes occur, and a little patch of another mineral which gives straight extinction and low polarization-tints—a pale greyish-buff—(? a form of chlorite). A less fissile specimen, from rather nearer the Col so far as the collector remembers, is a little hard, consists of 'antigorite' of both tints, rather foliated, together with powdered magnetite and some flakes (pale green and very feebly pleochroic, having a little opacite between the cleavages) which reach the blue of the second order.

<sup>1</sup> At the same time, after examining a rather numerous collection of fragments which Miss Raisin brought some years ago from this district, I think that the bulk of the rock, whether slaty or not, represents the augitic group. [T. G. B.]

A specimen in Miss Raisin's collection, sliced since these words were written, from a block on the right bank of the Zmutt Glacier, beneath the Matterhorn, also appears to consist of a serpentinized olivine (poor in iron) and a few grains of another mineral, probably once an enstatite, but now replaced by minute antigorite (*cf.* the specimen from Val Antigorio) which sometimes exhibits an approach to thorn-structure.

<sup>2</sup> This was collected (because of its curious look) so long ago as 1860.

Several analyses of Alpine serpentines are tabulated by Dr. M. E. Wadsworth,<sup>1</sup> and some by Miss E. Aston will be found in this Journal.<sup>2</sup> One of the latter contained an unusually-high percentage of nickel, but in other respects did not differ from the normal. The differences in these analyses (including the Sprechenstein specimens) seem insufficient as a basis for distinctions, and they all lie within the limits of variation due to the presence of this or that magnesian silicate or the conversion of them into serpentine.

## XII. SERPENTINES FROM JAPAN.

Through the kind offices of Prof. John Milne, F.R.S., one of us received, nearly twenty years ago, from Prof. Kotô a number of specimens of serpentine (dull green) from Japan. As all were rather seriously affected by pressure, and he was then desirous of studying unaltered types, none of them were sliced until he began to put together the notes for this paper. Each of the eight specimens examined under the microscope shows signs of pressure, but this appears, as a rule, to have acted less definitely in one direction than it has done in the Alps. Two or three have contained enstatite; one, much olivine with some augite; two others were probably peridotites; in one or two augite may have dominated, although this is not quite certain; in two the chlorite-like mineral, with dull-white polarization-tints, as already mentioned, is present, forming in one a rather distinct band. The serpentine generally occurs in fibrous flakes with low polarization-tints, but we find occasionally typical antigorite, and in part of one slice the rather bright-tinted variety with an oblique extinction at low angles.

## XIII. CHEMICAL CHANGES.

The chemical changes in the conversion of olivine and one or two ferromagnesian silicates into serpentines were discussed by J. Roth and have been explained by J. J. H. Teall.<sup>3</sup> If we take (for simplicity) the non-feriferous forms, their composition is as follows:—

Forsterite .....	2MgO	+	SiO <sub>2</sub> .
Enstatite .....	MgO	+	SiO <sub>2</sub> .
Augite (diopside) .....	(MgCa)O	+	SiO <sub>2</sub> .
Serpentine .....	3MgO	+	2SiO <sub>2</sub> + 2H <sub>2</sub> O.
Talc .....	3MgO	+	4SiO <sub>2</sub> + H <sub>2</sub> O.

Thus the conversion of two molecules of forsterite (4MgO + 2SiO<sub>2</sub>) into one of serpentine requires the removal of one molecule of magnesia and the addition of two of water—a slight increase of bulk. But ordinary olivine contains an appreciable quantity of iron which remains as an oxide, so the removal will be less and the

<sup>1</sup> 'Lithological Studies' Mem. Mus. Comp. Zool. Harv. vol. xi (1884) pp. xxiv-xxviii.

<sup>2</sup> Vol. lii (1896) pp. 454-56.

<sup>3</sup> 'British Petrography' 1888, chapt. vi, p. 104.

increase greater.<sup>1</sup> We may, therefore, say that the ratio of the silica to the magnesia is practically unaltered.

Two molecules of enstatite ( $2\text{MgO} + 2\text{SiO}_2$ ) become one of serpentine by the addition of one molecule of magnesia and two of water, and if the enstatite be ferriferous still more magnesia must be added; or, if the magnesia in the rock remain as before, some silica must be removed in adding water. If, for simplicity, we assume augite to contain equal amounts of magnesia and of lime, the conversion of two molecules of augite ( $\text{MgO} + \text{CaO} + 2\text{SiO}_2$ ) into serpentine requires the addition of two molecules of magnesia and the same of water and the removal of one of lime—or, in other words (apart from the water), this signifies the removal of a large amount of silica and lime from the rock—obviously the greater change. So it is not surprising to find augite more persistent than the other two minerals; especially since, as we can see from a table of analyses of diopside and sahlite, the lime generally exceeds the magnesia in the approximate ratio of 17 : 13. The evident fact that pressure (leading to reduction of volume) is favourable to the conversion of augite into serpentine (antigorite) is significant. It also follows, that to convert forsterite into talc requires the removal of more than half the magnesia and the addition of a little water, but if any iron be present the loss is not quite so great. When enstatite is altered into talc, either a little silica must be added with the water, or a corresponding amount of magnesia removed—a less serious change. The conversion of serpentine into talc means either the addition of two molecules of silica and the removal of one of water, or the removal of half the magnesia and much of the water. In regard to this, the frequent presence of a magnesian carbonate where this change has occurred may be significant.

#### XIV. GENERAL CONCLUSIONS.

These investigations, which we fear may have seemed rather prolix, into the production of serpentine from each of its parent minerals, and as a rock-constituent, justify, we trust, the following conclusions:—

(1) That a tint and pleochroism are accidental rather than essential characteristics of the variety of the mineral serpentine named antigorite.

(2) That, if low polarization-tints be regarded as an essential characteristic of antigorite, a closely-associated mineral must exist, which is distinguished only by greater brightness of these. If the minerals can be isolated and subjected to analysis (which we have not the means of applying), they may prove to be distinct: but the way in which, as described in the preceding pages, they seem to graduate one into the other, leads us to believe that they are varieties

<sup>1</sup> It is noteworthy that in gabbros where grains of olivine are converted into serpentine the neighbouring felspar is much cracked, as if by their swelling. Also, in regard to the chemical change, we may note the rather slow alteration of the non-ferriferous olivine in the diamantiferous breccia described above.

of a single mineral—antigorite. Both forms usually afford straight extinction, but it is occasionally oblique, though the angle is small. Thus, either the mineral is dimorphous, or its optical characters have been affected by pressure, or it is really monoclinic. Flakes, however, do occur which, while extinguishing obliquely at low angles, have a slightly-higher index of refraction. These probably represent a form of hornblende.

(3) That it is doubtful whether any hard-and-fast line can be drawn between the rather fibrous forms of the mineral in the ordinary serpentine-rocks and the mica-like (antigorite) of certain others.

(4) That the most typical antigorite occurs when the rock has been considerably affected by pressure, but that it becomes smaller and rather less typical when the pressure has been very great (that is, in the most slaty serpentines).

(5) That the 'gestrickte struktur' of the antigorite, so far as it exists (and it is mostly subjective), has no connection with the nearly-rectangular prismatic original cleavage of augite; the latter structure, curiously enough, being worse preserved than any other in the process of serpentinization. Typical antigorite, however, appears to be produced rather more readily from augite than from the allied ferromagnesian silicates, but its characteristic form is more directly a consequence of pressure<sup>1</sup> than of chemical composition, or, in other words, when this has acted, the mineral serpentine occurs in mica-like plates, instead of in rather irregular or flame-like flakes.

#### EXPLANATION OF PLATE XLV.

Fig. 1. Diamantiferous breccia ('Hard Blue') from Kimberley (specimen obtained by Sir J. B. Stone in 1894). (a) unchanged olivine; (b) shell of serpentine; (c) feather-like growth of serpentine. ( $\times 20$ , crossed nicols.) (See p. 693.)

2. Band of almost pure augite in a serpentine from north-east of Bonhomme, Vosges. (a) augite; (b) serpentinized olivine (shaded). ( $\times 20$ .) (See pp. 697-98.)

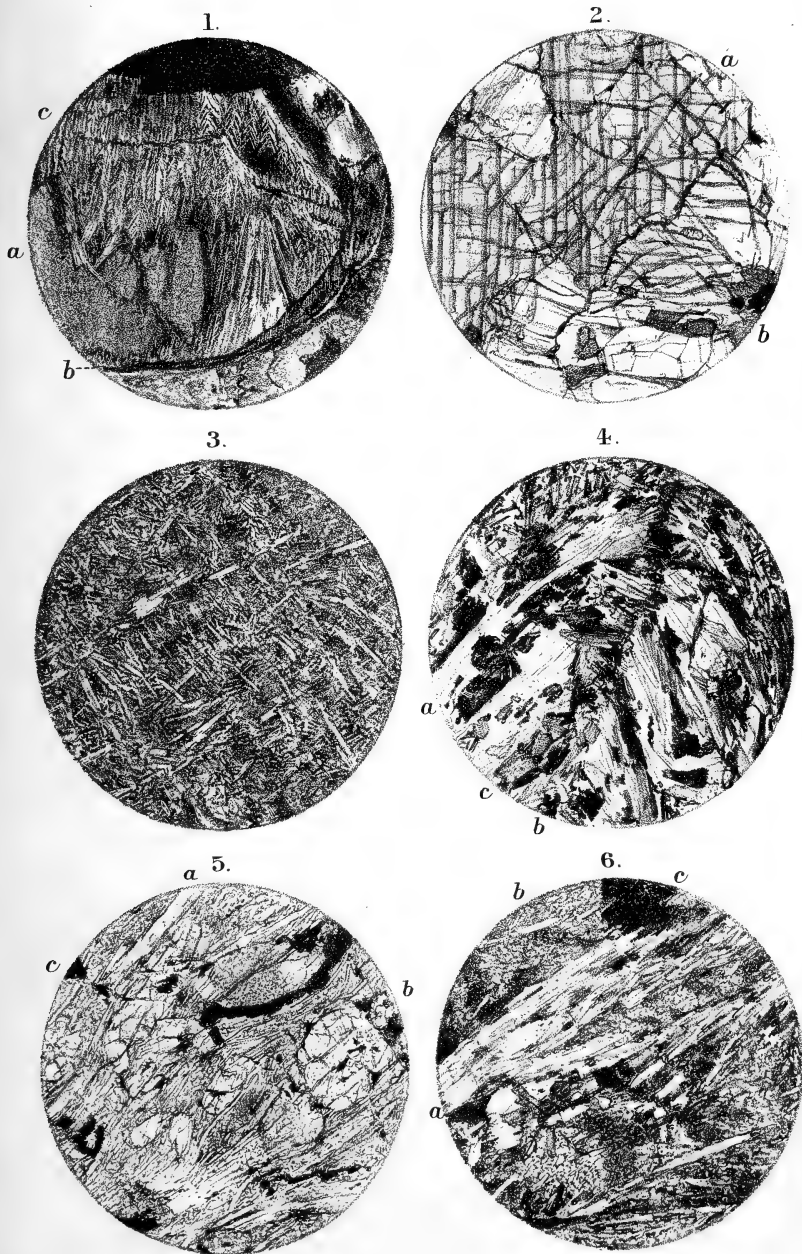
3. Antigorite-serpentine, Sprechenstein, Brenner. From one of the less-crushed lenticles, about 7 feet from the edge of the mass, representing the so-called 'thorn-structure.' ( $\times 25$ , crossed nicols.) (See p. 702.)

4. Antigorite-serpentine with puckered foliation: (a) antigorite. Of the non-flaky materials, the very dark (b) are iron-oxide (mostly magnetite) and the dusky (c) residual augite. ( $\times 25$ , crossed nicols.) (See p. 704.)

5. Antigorite-serpentine, from a boulder with a slightly-streaky structure on the right moraine of the Fee Glacier, Saas Fee, consisting largely of augite. (a) antigorite; (b) augite, represented not only by the granular clear mineral, but also by much of the dusty part not showing a mica-like structure; (c) magnetite. ( $\times 25$ .) (See p. 708.)

6. Antigorite-serpentine, from the summit of the Riffelhorn, Zermatt. (a) antigorite; (b) residual augite; (c) magnetite. ( $\times 25$ , crossed nicols.) (See p. 709.)

<sup>1</sup> F. Becke called attention to the connection of antigorite with pressure (as already stated) in 1894; but our conclusions were formed independently, as one of us had noticed it some time before that date.





## DISCUSSION.

The PRESIDENT referred to the interest that the Fellows must feel in having a paper laid before them, in which, besides much original information, there was a summary of the history of the progress made in a group of rocks upon which one of the Authors had thrown light thirty years ago.

Dr. TEALL remarked that the President had, to some extent, anticipated what he was about to say on the importance of the communication which had just been laid before the meeting. He feared that he could not throw much additional light on the subject. The main point appeared to be that, in addition to the serpentines derived from peridotites, another important group existed, wherein the structure was not the same, that was, the antigorite-serpentine group. This was of more widespread occurrence than had previously been supposed, and was largely composed of altered augitic rocks. His own experience, so far as it went, confirmed the Authors' conclusions. He would be glad to learn the Authors' views as to the origin of such augitic rocks as those from Canada: was it possible that they represented altered siliceous dolomites or rocks of a similar type?

Prof. BONNEY replied that he had meant to say that antigorite might come from olivine or enstatite (there was enstatite in the original Val-Antigorio rock), but that it came most readily from augite. The origin of the augitic rocks of Canada was too long a subject for the present occasion, but he did not believe that they had been formed in the way suggested by Dr. Teall.





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TO

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1906.  
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NOVEMBER 30th, 1905.

No. 244.

C. A. White

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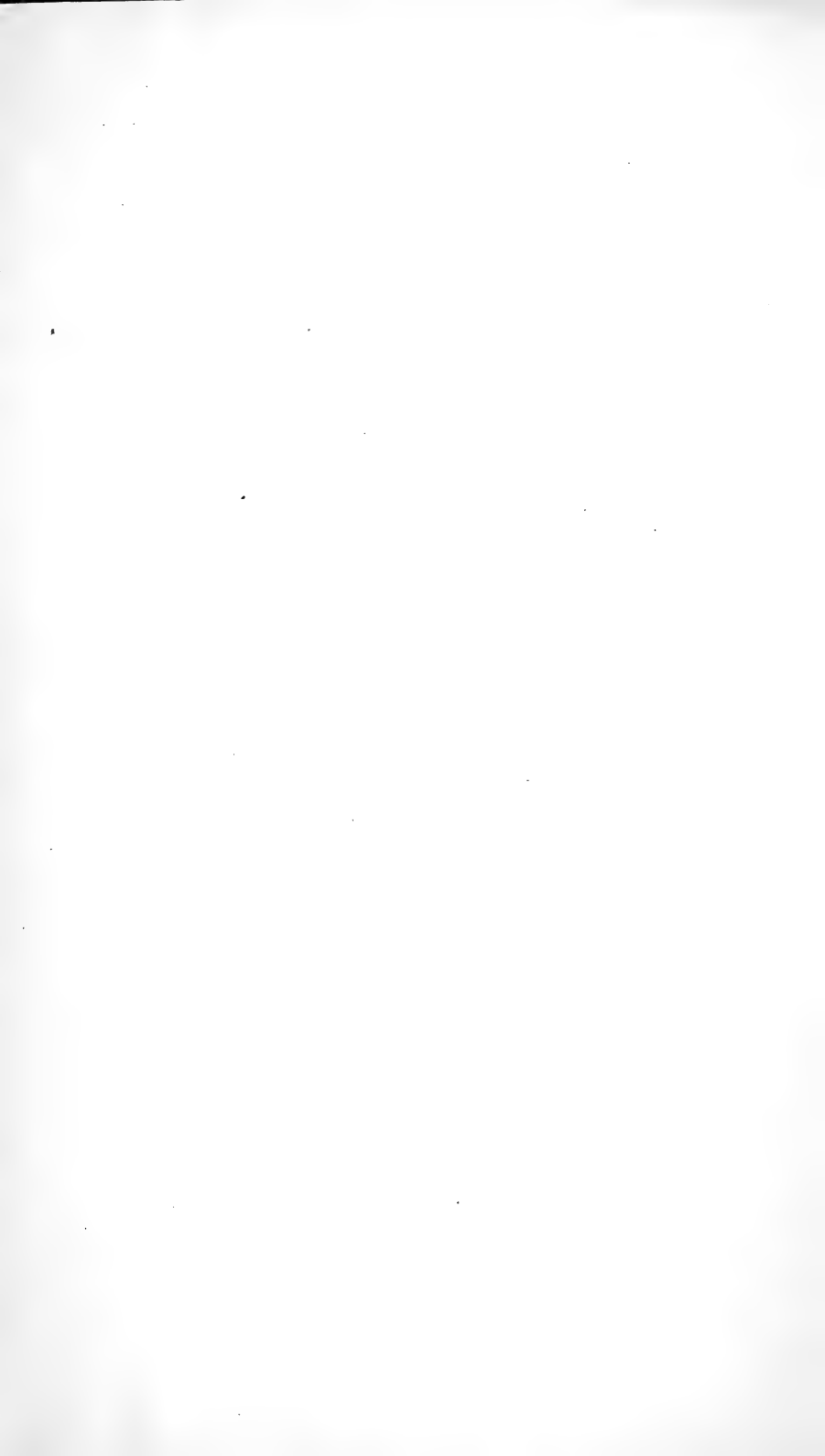
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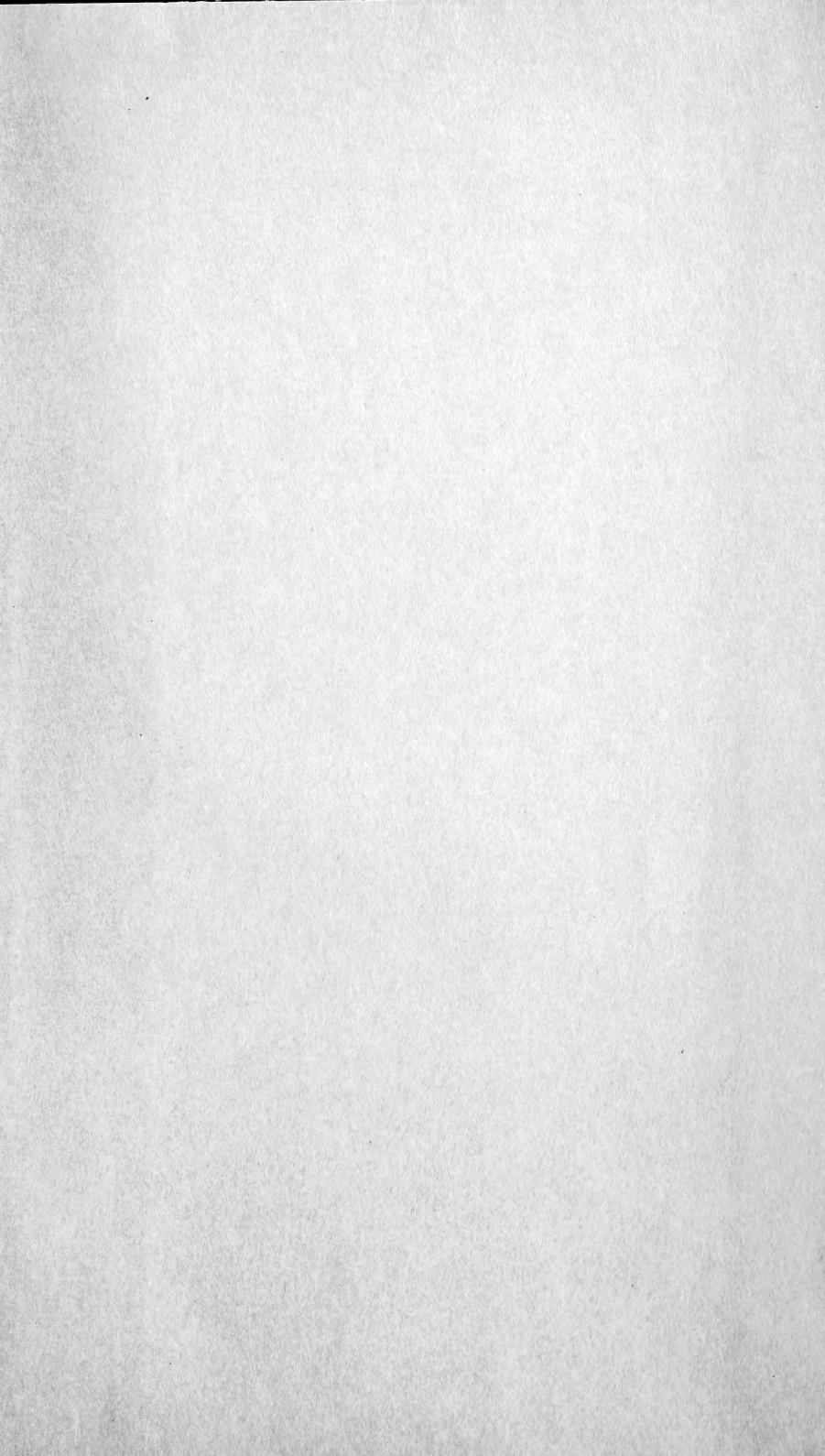
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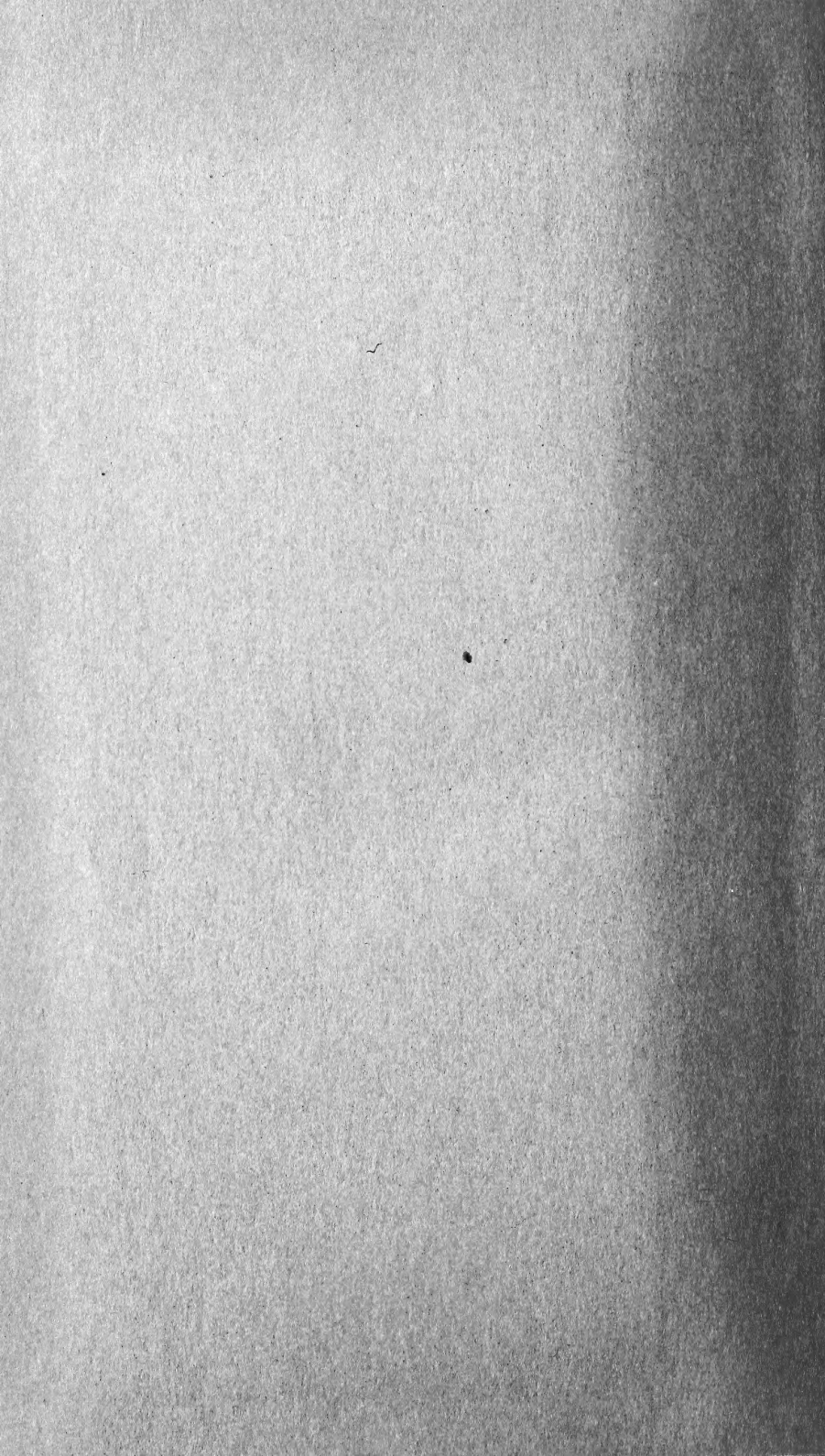
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